DTNSRDC/SPD-0795-01

ATLAS OF NAVAL OPERATIONAL ENVIRONMENTS: THE NATURAL MARINE ENVIRONMENT

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LEVEL II

DAVID W. TAYLOR NAVAL SHIP RESEARCH AND DEVELOPMENT CENTER

Bethesda, Md. 20084

ADA077033

ATLAS OF NAVAL OPERATIONAL ENVIRONMENTS: THE NATURAL MARINE ENVIRONMENT

by

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and

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SHIP PERFORMANCE DEPARTMENT

September 1979

DTNSRDC/SPD-0795-01

79 11 19 027

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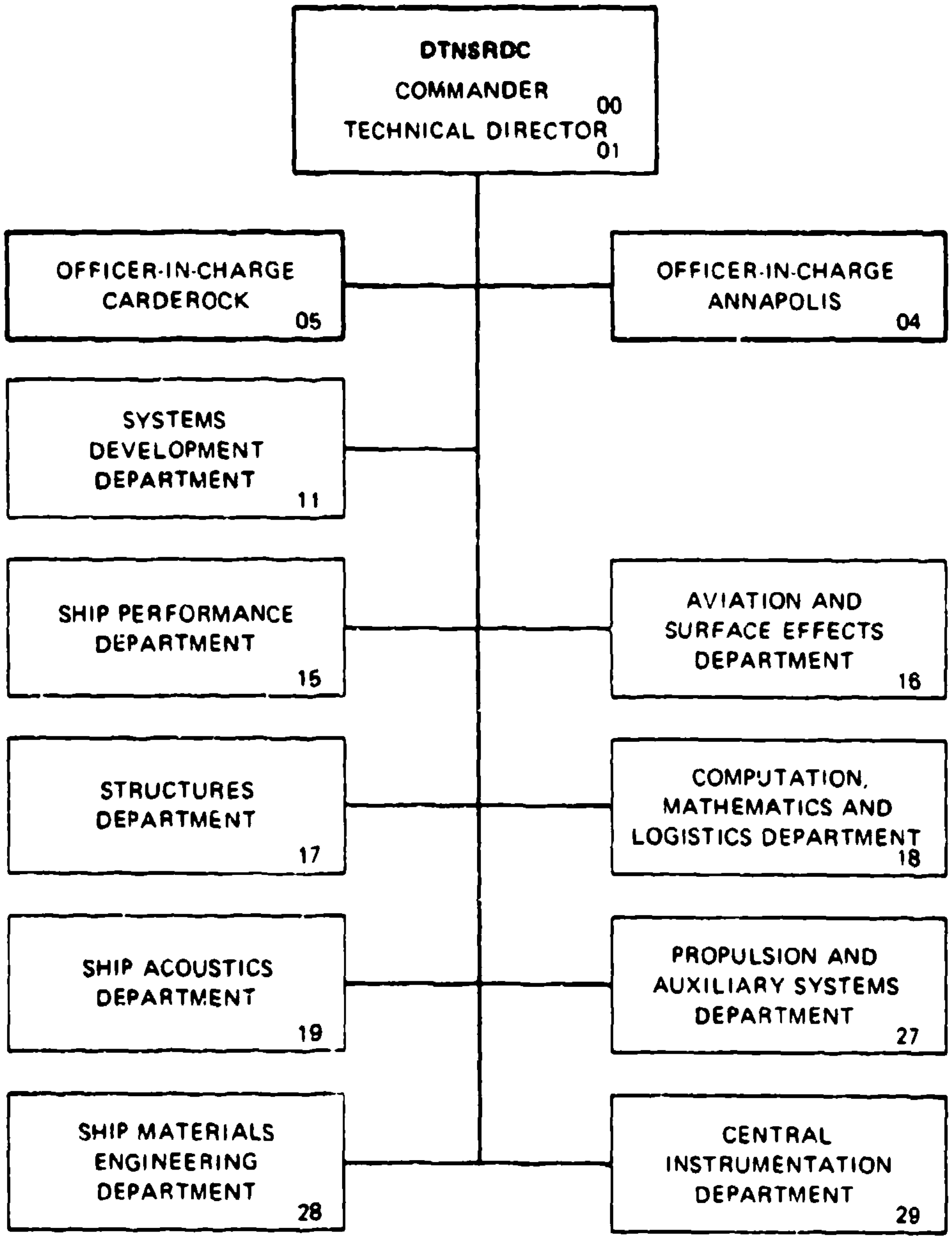

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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

14 ~~1. REPORT NUMBER~~ DTNSRDC/SPD-0795-01	2. GOVT ACCESSION NO.
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle) 6 ATLAS OF NAVAL OPERATIONAL ENVIRONMENTS; THE NATURAL MARINE ENVIRONMENT.	5. TYPE OF REPORT & PERIOD COVERED 9 Final rept.,
	~~6. PERFORMING ORG. REPORT NUMBER~~
7. AUTHOR(s) 10 Susan Lee Bales [redacted] Edward W. Foley	8. CONTRACT OR GRANT NUMBER(s) 12 342
9. PERFORMING ORGANIZATION NAME AND ADDRESS Ship Performance Department David W. Taylor Naval Ship R& D Center Bethesda, Maryland 20084	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Work Unit Nos. 1-1568-864, 1-1568-895, 1-1568-812
11. CONTROLLING OFFICE NAME AND ADDRESS Naval Ship Engineering Center Department of the Navy Washington, D.C. 20362	11 ~~12. REPORT DATE~~ Sep[redacted]79
	~~13. NUMBER OF PAGES~~ 350
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report) Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

9 1.14

16. DISTRIBUTION STATEMENT (of this Report)

APPROVED FOR PUBLIC RELEASE: DISTRIBUTION UNLIMITED

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Natural Environment
Ship Design
Operational Area
Wave Statistics
Combat Capability Assessment (CCA)

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

From the viewpoint of some ship designers, a fundamental deficiency in the current process by which naval combatants are designed is the lack of interface and feedback between the design of the major subsystems of the total ship. In order to address this deficiency, and in fact, to determine the feasibility of developing an integrated ship system design process, a research and development project was initiated by the Navy in 1976. The

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S/N 0102-LF-014-6601

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389 694

(Block 20 continued)

were proposed project leaders proposed the development of an "Atlas of Naval Operational Environments" which included both threat (man-made) and natural (those occurring in nature) environments which naval forces could be expected to encounter. The Atlas would be directed to the ship combat systems designer.

This report provides the natural environments required by the Atlas for nine global locations considered to be of importance for possible future naval operations (adversary encounters) in this century. The nine operational areas are located in or near

a. the Norwegian Sea,

b. the northern North Atlantic west of Scotland,

c. the eastern Mediterranean west of Cyprus,

d. the Japan Sea off Korea,

e. the Gulf of Aden off Saudi Arabia,

f. the southeastern North Atlantic off Guinea,

g. the North Pacific off the Aleutians,

h. the Caribbean south of Cuba, and

i. the Malacca Straits southeast of Singapore.

Worst season (wind and waves) atmospheric and surface environmental data are included for each area. Subsurface data as well as data for other global areas will be provided in future reports.

Individual environmental parameters which may impact generic ship missions are identified. Where possible, sensitivity of subsystems to various environmental parameters is discussed. A comparison of the severity of the worst seasons for each of the nine operational areas is made, and recommendations for picking the severest areas for purposes of Combatant Capability Assessment (CCA) modeling are given.

"Atlas of Naval Operational Environments: The Natural Marine Environment," by Bales and Foley, Report DTNSRDC/SPD-0795-01 (Sep 1979)

Errata

1. p. 17 - subtitle should read "Latitude, Longitude"
2. p. 24 - location should read "29.5°-30.5°E"
3. p. 24 - sea surface direction should be "W-NW"
4. p. K-2 - seventh line in last paragraph should read "These parameters"

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ABSTRACT

From the viewpoint of some ship designers, a fundamental deficiency in the current process by which naval combatants are designed is the lack of interface and feedback between the design of the major subsystems of the total ship. In order to address this deficiency, and in fact, to determine the feasibility of developing an integrated ship system design process, a research and development project was initiated by the Navy in 1976. The project leaders proposed the development of an "Atlas of Naval Operational Environments," or "Ship Designers Atlas," which included both threat (man-made) and natural (those occurring in nature) environments which naval forces could be expected to encounter. The Atlas would be directed to the ship combat systems designer.

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ADMINISTRATIVE INFORMATION

This report was prepared under the sponsorship of the Naval Ship Engineering Center (NAVSEC), Code 6174, Work Request Numbers WR75240, WR81537, and WR92518. It is identified by Work Unit Numbers 1-1568-864, 1-1568-895, and 1-1568-812 at the David W. Taylor Naval Ship Research and Development Center (DTNSRDC).

INTRODUCTION

The naval combatant is designed essentially by conducting a series of nearly independent, and sometimes even sequential, designs of the major subsystems of the total ship. Typically, the design of the weapons and other major combat systems is initiated 14 years before the final ship is introduced to the fleet. Seven years before fleet introduction, the hull design as well as the hull/weapons interface are initiated. The lack of sufficient quantitative interface between the design of each major ship subsystem (including the hull and the combat systems) has been recognized, and a project to develop the needed Combatant Capability Assessment (CCA) tools was initiated in 1976 under the technical leadership of NAVSEC 6174.

The initial impact of the CCA project will hopefully be to provide the combat subsystem designer with the necessary elements for building a rational procedure to design his particular subsystem. With such tools, the designer will find it possible to include the effects of hull dynamics as well as occurring and consistent natural and threat environments in his modeling of the combat subsystems. Additionally, the performance of the total ship can be assessed a priori to construction and introduction to the fleet. In the long run, the project may provide the naval ship design community with the groundwork for a more integrated ship subsystem design process. For example, it is not beyond the imagination to conceive of hull, communication, detection, missile launching, gunfire control, etc. subsystem designs that essentially complement, rather than restrict, each other from early concept through contract design studies.

The "Atlas of Naval Operational Environments" or the "Ship Designers Atlas," as it is sometimes called, is one product of the project. The operational environments are divided into essentially two, though not

totally independent, categories. The threat environments are currently under development by PRESEARCH, Inc., which is also responsible for developing the overall structure of the Atlas. The natural environments are being developed by DTNSRDC and are presented in this report for later incorporation into the Atlas.

Atmospheric and surface data for nine "hot spots" throughout the world are given in this report.* Subsurface data, essential to antisubmarine warfare considerations, will be treated in a later document. Additionally, data for at least seven other "hot spots," located primarily in the open ocean, will be provided in a subsequent report.

NINE OPERATIONAL AREAS

Figure 1 and Table 1 indicate the nine global locations considered to be potentially critical naval operational areas during the rest of this century. The locations were selected by NAVSEC 6174 and PRESEARCH, Inc.

The locations are essentially coastal, as opposed to open ocean, which, from the viewpoint of the natural environment, means a great deal of historical data is available. The primary data source of the reported atmospheric and subsurface data is the Naval Weather Service Detachment at the National Climatic Center in Asheville, North Carolina. Various publications of historic data have been used to construct much of the data of this report and are referenced as the data is presented.

PARAMETER IDENTIFICATION

The natural environment parameters which influence ship operations and are hence important to the ship designer are not always easy to identify. By far, the most well-known environmental sensitivity of the ship is that related to the wave action. However, it is also obvious that the wind is relevant. And further, such atmospheric qualities as humidity, cloud cover, and visibility are known to affect the behavior of certain combat systems as well as tactical decision making.

Table 2 has been prepared to provide a general guide as to which natural environment parameters are important to ship performance. The table was derived in consultation with various NAVSEC 6174, DTNSRDC,

*A preliminary draft report was first provided to the sponsor and the rest of the CCA community in April 1978. This report supersedes the earlier draft which should now be discarded.

Rockwell,* and Atlantic Research* personnel and is intended only as a generic description of ship mission dependence on natural environment.

As the sensitivity of ship subsystem performance with regard to all natural environment parameters is not well-known, it was decided to proceed initially by collecting as much data as possible for each parameter for each of the nine locations previously identified. It was assumed that the ship designer would somehow be able to select appropriate parameter occurrences for ship performance assessment purposes, a conservative though perhaps not irrational assumption. The selection of appropriate parameter occurrences is discussed in a subsequent section of the report entitled Guidelines for the Modeler.

DATA PRESENTATION

The surface natural environment data for the nine locations are presented in Appendices A through I. The alphabetic designation of each appendix corresponds to that given in Figure 1 and Table 1 for each location. Each appendix is divided into two sections. The first gives a narrative overview of the general climatology about the location. Seasonal and annual occurrences are noted as well as any unusual local phenomena. The second section provides the actual data distributions for natural environment parameters for the season (month) selected as the "worst" at that particular location.** The worst months have been determined by analysis of the historical data for the sea surface (wave height) and wind parameters and are listed in Table 3.

Appendix J provides the outline or order of the data types presented in the second sections of each of Appendices A through I. A brief description of how to read each figure is also given. In some cases, a particular data distribution type was not available (or there was insufficient data) for a given location. These cases are noted as they occur in Appendices A through I.

As locations A and B are relatively similar in overall climatology (due to their geographic proximity), the narratives for the two have been combined and the resulting one appears in Appendix A.

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*NAVSEC 6174 contractors for CCA modeling.

**Data for other seasons (months) are available from the References.

Appendix K provides data for electromagnetic phenomena for locations A through I. Unfortunately, very little data, as compared to that for the other parameters, was found for these phenomena. That which has been found is on a global-contour basis and by representative months of various seasons.

Appendix L provides miscellaneous properties not included in Appendices A through I. These include daylight/darkness and depth of wave action graphs as well as a chart of expected survival time in cold water. Also a sea state chart, developed for the winter North Atlantic (40 - 60°N) extracted from another report* and commonly used in ship design support studies (Top Level Requirement/Specification (TLR/TLS) development), has been included. An expression is also given for the wind gradient as a function of elevation above the sea surface.

It should be noted that the wave heights presented in Appendices A through I are visually observed heights which have been extracted from the Navy's historical data base of synoptic meteorological and oceanographic parameters. These heights can be converted to significant values using the Nordenström relationship provided in Appendix J. It is customary to use the significant value (average of one-third highest double amplitudes) when referring to the severity of the sea by the sea state chart given in Appendix L.

EXTREME VALUES

As implied earlier in the report, the nine operational areas to be included in the Atlas of Naval Operational Environments were selected almost exclusively from the system analyst's point of view. That is, the locations are the ones considered the most likely spots at which U. S. naval forces could be engaged in combat operations during the rest of this century. The initial (and primary) purpose of the Atlas is to provide the ship designer with the necessary tools to conduct rational Combatant Capability Assessments. Thus, it is with merit that the nine areas were selected based on careful study of the near-term world political, tactical, and

*Bales, S.L., "Sea Environment Manual for Ship Design," Report DTNSRDC/SPD-0720-01 (to be published in 1979).

strategic climate from the viewpoint of the U. S. as a world power and the defense of its allies.

It is relevant to note, however, that critical values of the properties of the natural environment are not necessarily achieved at each of the nine locations. Further, it is possible that important occurrences that occur elsewhere in the world ocean are never encountered at any of the nine locations. One such example of this would be the long swells which occur in the open ocean due largely to great fetch lengths and distant storms. The long swells can induce severe rolling in larger ships such as the typical aircraft carrier.

A brief side investigation has been conducted, therefore, to appraise the quality of the extreme cases of the surface and atmospheric natural environment parameters reported herein. The investigation is broken into two parts:

a. Examine probabilities of occurrence for selected natural environment parameters at each location. Compare values for each of nine locations. Identify location(s) which optimizes the occurrence of more severe parameter values.

b. Postulate other operational areas, perhaps in the open ocean, that may optimize severe occurrences. Compare with results of part a.

Before discussing the results of this investigation some comments regarding the quality of the data are in order. The data examined are for the worst seasons at each location as presented in Appendices A through I. Unfortunately some parameters may not be well represented, especially at the extremes, by the distributions currently available. Two important parameter types in this category are those dealing with winds and waves. The difficulty arises due to the inherent fair weather bias in the data. The data is developed from shipboard observations, and ships generally try to avoid areas of severe weather. Thus, observed extremes are reported somewhat less often than they occur. This fact, combined with the low probability of occurrence for extreme values, leads to a dubious sample size.

The side investigation was conducted in spite of the inherent problems with the data sources in regards to extreme values. Table 4 provides the

results of a ranking process applied to the worst season natural environments (surface and atmospheric) at Locations A to I. Table 5* provides the criteria by which the environmental parameters of each location were ranked on Table 4. For example, if the highest 5 percent of all wave height observations are less than 10 feet, the ranking assigned is benign or number 1. If the highest 5 percent of the observations are between 10 and 18 feet, the ranking assigned is moderate or number 2. For locations with the highest 5 percent of the observations exceeding 18 feet, a ranking of 3 or severe has been applied. The rankings listed in Table 5 were selected such that the locations of Table 4 fell into categories ranging from benign to severe, with the possible exception of superstructure icing where the criteria used were the same as defined for Figure 13 of Appendices A through I. The rankings applied to the locations have merit only when viewed relative to each other and thus the rankings do not necessarily represent a worldwide climatic ranking or indicate degradation to ship mission capabilities. For instance, a ranking of severe has been applied to locations where 10 percent or more of the low temperature observations during the worst month are less than 32 degrees Fahrenheit. A low temperature of 32 degrees Fahrenheit during a cold season month may, in fact, be quite benign for some world locations and may have little effect upon a given ship mission. This ranking for low temperature (as well as the other environment parameters of Table 4) is intended to be viewed relative to the other locations listed on Table 4 only.

Examining Table 4 for Locations A to I of the Atlas, several conclusions can be drawn concerning environmental extremes during the worst months. It is clear that the most severe wind and wave environments are associated with Locations A, B, and G. Although the worst months selected for each of the locations generally are during the cold weather season, a warmer environment is indicated for Location E with F, H, and I also indicating warmer temperatures. These warmer climate locations seem to be associated with more benign wind and wave environments. Air temperatures seem to be lowest for Locations D and G with A and B also indicating lower

*Because the data reported herein was developed as long ago as 1976, and in keeping with the sponsor's wishes at the time, metric units have not been used in this report.

air temperatures. Conversely, these colder locations seem to be associated with more severe wind and wave environments, although Location D indicates moderate wind and wave conditions (predominating winds are from the land direction resulting in limited fetch). Larger amounts of precipitation do not seem to be directly associated with any of the other environmental parameter extremes including cloud cover. Low sea level pressure is generally associated with heavy weather phenomena and Table 4 shows Locations A and G exhibiting severe low pressure values. Locations A and G are, as previously mentioned, classified as severe wind and wave environments on Table 4. High sea level pressure is generally associated with fair weather and it is therefore somewhat contradictory to find Location B classified as severe high pressure, since Location B is also classified as a severe wind and wave environment. Location B is, however, classified as moderate for low sea level pressure. This anomaly is due in part to the inherent subjectivity in the ranking criteria identified in Table 5.

Considering the overall environment as characterized by all the parameters of Table 4, the most severe environment seems to be Location G. Locations A and B are also severe, although they are somewhat less severe than Location G.

In addition to the nine locations of the Atlas, Table 4 also provides rankings for two open-ocean areas. Location J (at 50°N, 145°W) is in the North Pacific near the Gulf of Alaska and Location K (at 48°N, 30°W) is in the middle North Atlantic along a major New York to London shipping route. Upon examination of the data (References 1 and 2),* January was found to be the worst month for both locations. Of these two locations, Location J seems to have the most severe climate and indeed compares to the severity of Location G. From the rankings of Table 4 and examination of the data (References 1 and 5), it is not possible to reliably ascertain which Location (G or J) has the most severe environment. Location J data indicated no increase in the probability of long wave periods when compared to Location G, even though Location G is sheltered to the north by the Aleutians.

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*A complete listing of references is given on pages 14 and 15.

In summary, the major environmental parameters for the locations of the Atlas (A through I) were compared and Location G was identified as the more severe environment. Locations A and B were also noted for severe environments. Examination of two open-ocean locations (J and K) did not lead to the discovery of a more severe environment; however, the joint occurrences of different environmental parameters was seen to vary somewhat. Within the context of near-term combat assessment models as well as existing natural environment data bases, the nine locations in the current Atlas may adequately cover the natural environments in which naval ships are expected to operate. However, ongoing work to develop improved wind and wave climatological data bases indicates that some phenomena (such as extreme values, persistence or duration of events, etc.) may not be adequately described in the current work. As improved natural environment information becomes available, the representativeness of the geographic coverage of this Atlas should be reviewed and modified as necessary.

GUIDELINES FOR THE MODELER

All naval combatants must operate in at least one of three regions, for example,

a. below the surface of the sea
b. at the interface of the sea surface and the atmosphere
c. above the sea (in the atmosphere)

In order to design and model some combat systems, it may be necessary to consider at least two of these regions simultaneously. Were multidimensional distributions of all of the environmental parameters presented in the appendices available, the modeler's task of selecting consistent* environments might prove easier (if he could manage such an enormous data array). At present, in some cases, it is difficult to model different parameters in the same region much less to consider a second region as may be required by combat systems designers.

*By consistent is meant the fact that the values selected for various different environmental parameters could in reality co-occur. An example of an inconsistent environment is one in which it is snowing while the air temperature is 90°F.

The most rigorously modeled natural environment parameters at present are those needed to design the hull, for example wave height, wave period, and wave direction. The state-of-the-art in seaway modeling, as applied to naval ship design practice, is provided in another report.* As a practicality, three approaches are suggested for inclusion of all environmental parameters in ship design.

APPROACH 1

Identify critical environmental parameters for the specific combat subsystem. Model each in turn (or simultaneously if possible) for specified occurrences (e.g., most probable values).

APPROACH 2

Identify critical environmental parameters (wave height and period) for hull responses. Using wind direction as the common parameter, select other probable values of wind speed, visibility and ceiling height, air temperature, precipitation, and fog. For example, for a given wave period, select the most probable wave height (Figure 1f).** For that wave height, select the most probable wind direction (Figure 1c) and the most probable wind speed (Figure 2a). For that wind direction, select the most probable visibility range (Figure 3c) (and from that ceiling height (Figure 3d)), air temperature (Figure 6c), precipitation occurrence (Figures 7b and 7c), and fog occurrence (Figure 10a).***

APPROACH 3

Using time of day as a common factor, select most probable values for wind direction (Figure 2c), wind speed (Figures 2d and 2f), visibility (Figure 3b), good cloud condition occurrence (Figure 5c), air temperature (Figure 6b), relative humidity (Figure 6f), precipitation occurrence

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*Bales, S.L., "Sea Environment Manual," Report DTNSRDC/SPD-0720-01 (to be published in 1979).

**Figure numbers are of data graphs given in Appendices A through I.

***Though most probable values were used in this example, more or less rare occurrences could likewise be used.

(Figure 7c), and ceiling height (Figure 9b). From the values selected for wind direction or wind speed, the wave height and thence period values can thence be determined.

COMMENTS

Obviously, each of the three suggested approaches produces potentially inconsistent environments. However, the limits of marine environment data bases currently available permits only a few options to the modeler for describing a total marine environment. The use of Monte Carlo techniques is also a possible approach, however, for design purposes, this could produce misleading results. For example, the likelihood of never selecting the "worst," but realistic combination of critical values is rather high. Further, the use of any one of the three approaches could provide potentially conservative results if it is assumed that all parameters can co-occur at the levels (most probable) selected. The use of most probable values has been suggested but mean or extreme values could likewise be chosen.

As a further guide for the modeler, Tables 6 through 14 are provided. These tables summarize the data in Appendices A through I respectively, by listing mean, median, most probable and boundary values for the various environmental parameters. Where possible, boundary values are given in Min, Max values; 95 percent of all observed natural environment values exceed Min values, 5 percent of all observed natural environment values exceed Max values. Thus, 90 percent of all values fall within the Min, Max range. The mean is the average of all values while the most probable is the one which occurs most often. Together, these two parameters provide an idea of the "shape" of the distribution of occurrences. For example, if the most probable value is less than the mean, the distribution of occurrences is skewed to the lower values. If the most probable value is greater than the mean, the distribution of all occurrences is skewed to the higher values. If the most probable and mean values coincide, the distribution of occurrences may be of the normal type.

Though it is beyond the scope of the current work to develop an algorithm for simultaneous sampling of the natural environment parameters, a few general rules of thumb are offered as an aid to the modeler. These

guidelines are generally derived by simple common sense and can be used to avoid the specification of physically unrealizable situations. Upon selection of a set of values for the critical environmental parameters, these guidelines can be used to assess the viability of the total data set:

1. Winds from the north are accompanied by colder temperatures, while winds from the south are accompanied by warmer temperatures.
2. Locally generated waves generally propagate in the direction of the wind. Swell waves may propagate into the local area from any distant storm area.
3. Longer period waves (> 13 seconds) will propagate into a local area from open-ocean, rather than coastal, directions.
4. Waves are dependent upon wind speed, wind duration, and fetch. Therefore, higher waves indicate persistent, high winds blowing over distances of 100 nautical miles or more.
5. Poor visibility is frequently accompanied by cloudiness and precipitation.
6. High relative humidities, $\geq$ 90 percent, as well as sea surface temperatures in excess of the air temperature, may accompany fog.
7. High winds are not accompanied by fog.
8. Generally, solid precipitation falls when the air temperature is $\leq$ 32°F.
9. Lower atmospheric pressures, $\leq$ 1000 millibars, are accompanied by lower air temperatures, higher wind speeds, and greater likelihood of precipitation.

FUTURE WORK

This report is by no means conclusive on the subject of natural environments for inclusion in the Atlas of Naval Operational Environments. Several areas which require further attention are

a. Definition of rain rate and rain drop size for precipitation at sea
b. Persistence (duration) of critical levels of occurrence
c. Procedures for developing consistent "total" environments

d. Improved data for electromagnetic properties

e. Parameter identification and data distributions for subsurface properties

f. Modification of included data as improved climatological data bases become available

g. Expansion of global coverage if new data indicate current locations overlook some important phenomena

It is expected that each of these items will be addressed during Fiscal Years 1979 and 1980 and that other reports will be published as results become available.

It is anticipated that the Atlas will eventually be sufficiently complete and credible to support all phases of the ship design/acquisition process. For example, the Atlas will ultimately provide a consistent baseline for defining requirements, developing specifications, and conducting validations of the entire ship system. Thus, the Atlas is envisioned to provide direct support to the development of required design/acquisition documentation such as the Mission Element Need Statement (MENS), Operational Requirements (OR), Top Level Requirements (TLR), Development Proposal (DP), Top Level Specifications (TLS), and Test and Evaluation Master Plan (TEMP). Therefore, an additional item of future work is the construction of an Atlas format which is readily applicable to both synthesis and analysis of ship performance parameters.

ACKNOWLEDGMENTS

The diligent work of Mr. Wah Lee of DTNSRDC is greatly appreciated. His efforts have eliminated many inconsistencies and errors in the data presented in the Appendices. Appreciation is also expressed to LCDR Dan LePore and Mr. Jim Ownbey, both of the Naval Weather Service Detachment (NWSD) in Asheville, North Carolina, for their assistance in accessing the Navy's historic synoptic meteorological and oceanographic data base. Additionally, the efforts of Ms. Joyce Voelker, Mr. Richard Bishop, and Mr. John Charles, all of DTNSRDC, and Mr. Paul Schmitt and Ms. Theresa Nightengale, both of ORI, Inc., in the detailed preparation of the many data graphs is also appreciated. The assistance of Dr. Michael Chi and Mr. Eddie Neal of CHI Associates, Inc. in the literature search required to write the climatological overviews of Appendices E to I is likewise appreciated.

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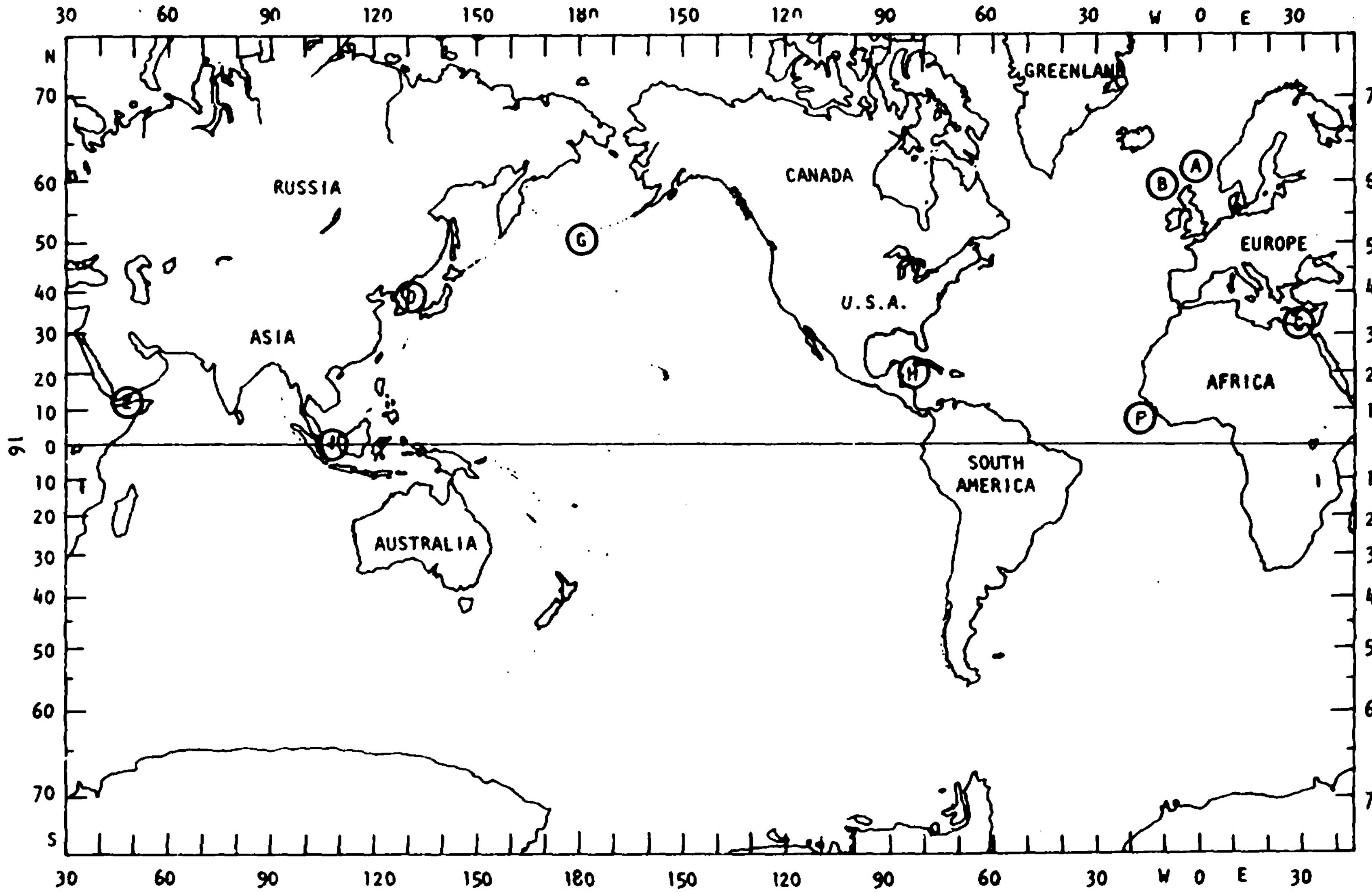

Figure 1 - Nine Potential Naval Operational Areas

TABLE 1 - OPERATIONAL AREA IDENTIFICATION

Location ID	Longitude, Latitude	Description
A	63°N, 2°W	Northern Northeast Atlantic (off Norway)
B	58°N, 12°W	Northern North Atlantic (off Scotland)
C	33°30' - 35°0'N, 29°30' - 30°30'E	Eastern Mediterranean (off Cyprus)
D	39°N, 129°E	Japan Sea (off Korea)
E	12°N, 46°30'E	Gulf of Aden (off Saudi Arabia)
F	9°30'N, 16°0'W	Southeastern North Atlantic (off Guinea)
G	50°N, 180°W	North Pacific (off the Aleutians)
H	20°45' - 21°50'N, 80° - 86°W	Caribbean (off Cuba)
I	0°N, 106°E	Strait of Malacca (off Singapore)

TABLE 2 - NATURAL ENVIRONMENT VERSUS SHIP FUNCTION

	Speed	Maneuverability	Detection and Communication Systems (Radar, Helo, etc.)	Defense (Weapons)	Ship Tactics*
Sea Surface Wave height, period, direction (currents)	x	x		x	x
Surface Winds Wind speed, direction	x	x		x	x
Visibility			x	x	x
Cloud Cover			x	x	x
Ceiling Height			x		x
Precipitation			x	x	x
Fog			x	x	x
Humidity			x	x	x
Temperature			x		x
Sea Level Pressure			x		x
Storm	x	x	x	x	x
Ice Concentration	x	x			x
Superstructure Icing	x	x	x	x	x
Refractivity Profile			x		x
Ducting			x		x
Ionispheric Data			x		x

*Nominally, ship tactical decisions can be influenced by any environmental parameter which impacts any ship function.

TABLE 3 - MONTHS OF SEVEREST WAVE/WIND CONDITIONS

Location ID	Severest Month (Wave/Wind Conditions)
A	February
B	February
C	January
D	December
E	July
F	August
G	February
H	January
I	January

TABLE 4 - WORST SEASON ENVIRONMENTAL COMPARISON

	Location										
	A	B	C	D	E	F	G	H	I	J	K
Sea Height	3	3	2	2	1	1	3	2	1	3	3
Long Wave Periods	2+	3+	2	1	1	1	3	1	1	3+	3
Mean Wind Speed	3	3	2	2	2	2	3	2	1	3	3
Maximum Wind Speed	3	3	2	2	1	1	3	1	1	3	3
Low Air Temperature	2	2	1	3	1	1	3	1	1	2	2
High Air Temperature	1	1	1	1	3	2	1	2	2	1	1
Poor Visibility	3	2	1	1	3	1	3	1	1	3	2
Cloud Cover	3	3	1	2	1	3	3	1	2	3	2
Precipitation	2	2	1	3	1	3	3	1	2	3	3
Low Humidity	1	2	3	3	2	1	2	2	1	2	2
High Humidity	3	3	2	1	1	2	3	1	1	1	1
Fog	2	2	2	1	2	1	*	*	2	*	*
Superstructure Icing	2	1	1	2	1	1	2	1	1	2	1
Low Pressure	3	2	1	1	2	1	3	1	1	3	3
High Pressure	2	3	2	2	1	1	2	2	1	3	2
Thunderstorms	1	2	3	1	2	3	2	1	2	2	2
Ducting	2	2	3	2	2	2	1	3	3	1	1

1 = Benign 2 = Moderate 3 = Severe

*No data available.

+The data for these locations were rounded to the nearest percent making an exact determination of the percentage difficult and thus the rankings are somewhat less reliable.

TABLE 5 - WORST SEASON RANKING CRITERIA

		-1- Benign	-2- Moderate	-3- Severe
Sea Height	Max 5% of data	<10 ft	≥10 ft	≥18 ft
Long Wave Periods	Max 3% of data	<12 sec	≥12 sec	≥13 sec
Mean Wind Speed	Mean of data	<10 knots	10-20 knots	>20 knots
Maximum Wind Speed	Max 1% of data	≤33 knots	34-47 knots	≥48 knots
Low Air Temperature	Lowest 10% of data	>40°F	32-40°F	<32°F
High Air Temperature	Highest 10% of data	<80°F	80-90°F	>90°F
Poor Visibility	<2 Nautical Miles	<3% of data	3-5% of data	>5% of data
Cloud Cover	8 & Obscured	<20% of data	20-40% of data	>40% of data
Precipitation	Occurring	<10% of data	10-20% of data	>20% of data
Low Humidity	10% or more of data	>70% RH*	60-70% RH	<60% RH
High Humidity	10% or more of data	<90% RH	90-95% RH	>95% RH
Fog	Occurring	<1% of data	1-5% of data	>5% of data
Superstructure Icing	Ranking procedure is the same as defined on page A-5			
Low Pressure+	10% or more of data	>1000 MB	999-1000 MB	<990 MB
High Pressure+	10% or more of data	<1020 MB	1020-1030 MB	>1030 MB
Thunderstorms	Occurring	≤.3% of data	>.3 to 1% of data	≥1% of data
Ducting	Geographic Location	Open Ocean	Coast	Coastal

*Relative Humidity

+Sea Level Atmospheric Pressure in Millibars

TABLE 6 - SURFACE NATURAL ENVIRONMENT FOR LOCATION A

Season: Winter (February); Location: A, Norwegian Sea, 63° N, 2°W

Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface					
Sig. Wave Ht., Ft.	1	6.5	15	7.5	6
Wave Period, sec	3	4.5	11.5	6	4.5
Direction	-	-	-	-	SE
Swell Height, ft	-	5.5	-	6	6
Swell Direction	-	-	-	-	S - SW
Winds					
Speed, knots	4	18	42	20	14
Corresponding Mean Sig. Wave Ht., Ft	2	6.5	14.5	7	6
Direction	-	-	-	-	SW - W
Visibility, nautical miles	2	6	25	8	10
Cloud Cover					
Total clouds, in eighths of sky obscured	2	7	8	6.5	8
Low clouds, in eighths of sky obscured	1-2	6	8	6	8
Precipitation (Occurrence)	All Precipitation 17% of Time Snow 7% of Time				
Relative Humidity, %	65	86	98	86	-
Air Temperature, °F	32	42	48	42	-
Surface Water Temperature, °F	38	44	47	44	-
Sea Level Pressure, millibars	970	1,008	1,035	1008	-
Ice	None	None	None	None	None
Surface Refractivity	-	-	-	-	314

TABLE 7 - SURFACE NATURAL ENVIRONMENT FOR LOCATION B

Season: Winter (February); Location: B, North Atlantic Ocean, 58° N, 12° W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface					
Sig. Wave Ht., Ft.	1	6.5	14.5	7.5	6
Wave Period, sec	2-3	4.5	11-12	6	4.5
Direction	-	-	-	-	S - SE
Swell Height, ft	1	8	14	9	8.5
Swell Direction	-	-	-	-	-
Winds					
Speed, knots	5	20	46	23	20
Corresponding Mean Sig. Wave Ht., Ft	3	7	13	9	7
Direction	-	-	-	-	S - SW - W
Visibility, nautical miles	1-2	7.5	25	9	10
Cloud Cover					
Total clouds, in eighths of sky obscured	1	6	8	6	6
Low clouds, in eighths of sky obscured	2	6	8	5.5	6
Precipitation (Occurrence)	All Precipitation 15% of the Time Snow 7% of the Time				
Relative Humidity, %	62	80	95	80	-
Air Temperature, °F	37	46	50	46	-
Surface Water Temperature, °F	45	47	52	47	-
Sea Level Pressure, millibars	967	1,012	1,042	1,012	-
Ice	None	None	None	None	None
Surface Refractivity	-	-	-	-	319

TABLE 8 - SURFACE NATURAL ENVIRONMENT FOR LOCATION C

Season: Winter (January); Location: C, Eastern Mediterranean Sea, 33.5° - 35° N, 29.5° - 30.5° N					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface					
Sig. Wave Ht., Ft.	1	5	8.5	4.5	4
Wave Period, sec	2-3	4	10	4.5	4.5
Direction	-	-	-	-	W - NW
Swell Height, ft	No data	No data	No data	No data	No data
Swell Direction	No data	No data	No data	No data	No data
Winds					
Speed, knots	2	14	41	13	11
Corresponding Mean Sig. Wave Ht., Ft	2	5	11.5	5	4.5
Direction	-	-	-	-	W - NW
Visibility, nautical miles	5	10	25	10	10
Cloud Cover					
Total clouds, in eighths of sky obscured	1	4.5	8	4	5-7
Low clouds, in eighths of sky obscured	1	4	7	3.5	1
Precipitation (Occurrence)	All Precipitation 8% of the Time				
Relative Humidity, %	55	71	88	71	-
Air Temperature, °F	43	59.5	76	59.5	-
Surface Water Temperature, °F	59	62.5	66	62.5	-
Sea Level Pressure, millibars	1,005	1,015	1,025	1,015	-
Ice	None	None	None	None	None
Surface Refractivity	-	-	-	-	319

TABLE 9 - SURFACE NATURAL ENVIRONMENT FOR LOCATION D

Season: Winter (December); Location: D, Sea of Japan, 39° N, 129° E					
Natural Environment	*Minimum* (5 Percentile)	*Median* (50 Percentile)	*Maximum* (95 Percentile)	Mean	Most Probable
Sea Surface					
Sig. Wave Ht., Ft.	1	5	10	4.5	5
Wave Period, sec	2	4	9	4	4
Direction	-	-	-	-	N - NW
Swell Height, ft	No data	No data	No data	No data	No data
Swell Direction	No data	No data	No data	No data	No data
Winds					
Speed, knots	5	14	34	14	14
Corresponding Mean Sig. Wave Ht., Ft	-	-	-	-	-
Direction	-	-	-	-	W - NW
Visibility, nautical miles	4	10	25	8	10
Cloud Cover					
Total clouds, in eighths of sky obscured	1	4	8	3	1
Low clouds, in eighths of sky obscured	1	4	8	3	1
Precipitation (Occurrence)	All Precipitation 21% of the time Snow 7.6% of the time				
Relative Humidity, %	45	73	90	73	-
Air Temperature, °F	17	39.5	64	39.5	-
Surface Water Temperature, °F	-	-	-	46	-
Sea Level Pressure, millibars	1,005	1,023	1,025	1,023	-
Ice	No data	No data	No data	No data	No data
Surface Refractivity	-	-	-	-	310

TABLE 10 - SURFACE NATURAL ENVIRONMENT FOR LOCATION E

Season: Summer(July) ; Location: E, Gulf of Aden, 12^0N , 46.5^0 E					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface					
Sig. Wave Ht., Ft.	1	3	7	3.5	2
Wave Period, sec	2	4	9	5	4
Direction	-	-	-	-	SW
Swell Height, ft	-	-	-	-	-
Swell Direction			Data not available		
Winds					
Speed, knots	2	11	25	12	11
Corresponding Mean Sig. Wave Ht., Ft	2	4	6	5	4
Direction	-	-	-	-	S-SW-W
Visibility, nautical miles	1-2	8	25	8	10
Cloud Cover					
Total clouds, in eighths of sky obscured	1	2	8	3	1
Low clouds, in eighths of sky obscured	1	2	7-8	2.5	1
Precipitation (Occurrence)	All Precipitation 2% of the time				
Relative Humidity, %	62	67	90	67	-
Air Temperature, ^oF	80	86	95	86	85-88
Surface Water Temperature, ^oF	72	82	87	82	-
Sea Level Pressure, millibars	997	1,002	1,007	1,002	-
Ice	None	None	None	None	None
Surface Refractivity	-	-	-	-	379

TABLE 11 - SURFACE NATURAL ENVIRONMENT FOR LOCATION F

Season: Summer (August); Location: F, Gulf of Guinea, 9.5° N, 16° W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface					
Sig. Wave Ht., Ft.	1-2	4	7	5	3
Wave Period, sec	1-2	4	11	6	4
Direction	-	-	-	-	N-NE-W
Swell Height, ft					
Swell Direction		Data not available			
Winds					
Speed, knots	4	11	28	11	14
Corresponding Mean Sig. Wave Ht., Ft	3	4	5	4	4
Direction	-	-	-	-	S-SW-W
Visibility, nautical miles	2	8	25	8	10
Cloud Cover					
Total clouds, in eighths of sky obscured	2	7	8	6	7-8
Low clouds, in eighths of sky obscured	1	6	7-8	5	7-8
Precipitation (Occurrence)	Heavy rainfall --20% of the time				
Relative Humidity, %	75	85	95	85	-
Air Temperature, °F	75	79	83	79	77-80
Surface Water Temperature, °F	75	79	81	79	-
Sea Level Pressure, millibars	1,010	1,015	1,018	1,015	-
Ice	None	None	None	None	None
Surface Refractivity	-	-	-	-	362

TABLE 12 - SURFACE NATURAL ENVIRONMENT FOR LOCATION G

Season: Winter (February); Location: G, North Pacific Ocean, 50° N, 180° W

Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface					
Sig. Wave Ht., Ft.	2	6	16	7	6
Wave Period, sec	4	7	12	8	8-9
Direction	-	-	-	-	SW-W
Swell Height, ft		Data not available			
Swell Direction		Data not available			
Winds					
Speed, knots	5	18	40	18	17
Corresponding Mean Sig. Wave Ht., Ft	-	-	-	-	-
Direction	-	-	-	-	SW-W
Visibility, nautical miles	1	6	25	7	8
Cloud Cover					
Total clouds, in eighths of sky obscured	1	7	8	6	8
Low clouds, in eighths of sky obscured	1	6	8	5	8
Precipitation (Occurrence)	All Precipitation 30% of the Time Snow 20% of the Time				
Relative Humidity, %	60	85	97	85	-
Air Temperature, °F	30	37	40	37	-
Surface Water Temperature, °F	32	37	42	37	-
Sea Level Pressure, millibars	975	1,000	1,025	1,000	-
Ice	Moderate*	superstructure icing more than 6% of the time			
Surface Refractivity	-	-	-	-	326

*Buildup of less than 1/10-in. per hour (derived from observations with temperature <28°F and wind speed ≥ 13 knots).

TABLE 13 - SURFACE NATURAL ENVIRONMENT FOR LOCATION H

Season: Winter (January); Location: H. Caribbean Sea, 20.75° - 21.5° n, 80° - 86° W					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface					
Sig. Wave Ht., Ft.	1.5	4	8	5	4.5
Wave Period, sec	3	5	10	6	6
Direction	-	-	-	-	E
Swell Height, ft	No data	No data	No data	No data	No data
Swell Direction	No data	No data	No data	No data	No data
Winds					
Speed, knots	4	14	24	12	14
Corresponding Mean Sig. Wave Ht., Ft	No data	No data	No data	No data	No data
Direction	-	-	-	-	E
Visibility, nautical miles	3	7	25	7	8
Cloud Cover					
Total clouds, in eighths of sky obscured	1	4	7-8	4	1
Low clouds, in eighths of sky obscured	1	4	7-8	3	1
Precipitation (Occurrence)	All Precipitation 5% of the time				
Relative Humidity, %	60	75	90	75	-
Air Temperature, °F	72	76	83	76	-
Surface Water Temperature, °F	76	79.5	83	79.5	-
Sea Level Pressure, millibars	1,015	1,017	1,025	1,017	-
Ice	None	None	None	None	None
Surface Refractivity	-	-	-	-	351

TABLE 14 - SURFACE NATURAL ENVIRONMENT FOR LOCATION I

Season: Winter (January); Location: I, Strait of Malacca, 0° N, 106° E					
Natural Environment	Minimum (5 Percentile)	Median (50 Percentile)	Maximum (95 Percentile)	Mean	Most Probable
Sea Surface					
Sig. Wave Ht., Ft.	1	3	6	3	2.5
Wave Period, sec	2	4	8	4	4
Direction	-	-	-	-	N-NE
Swell Height, ft		Swell not expected			
Swell Direction		Swell not expected			
Winds					
Speed, knots	2	9	20	10	9
Corresponding Mean Sig. Wave Ht., Ft	2	3	4	3	3
Direction	-	-	-	-	NW-N-NE
Visibility, nautical miles	5	8	25	10	10
Cloud Cover					
Total clouds, in eighths of sky obscured	1	6	8	6	6
Low clouds, in eighths of sky obscured	1	4	7-8	4	3.5
Precipitation (Occurrence)	All Precipitation 12% of the time				
Relative Humidity, %	75	80	83	80	-
Air Temperature, °F	75	80	83	80	-
Surface Water Temperature, °F	77	82	85	82	
Sea Level Pressure, millibars	1,007	1,009	1,011	1,009	-
Ice	None	None	None	None	None
Surface Refractivity	-	-	-	-	375

APPENDIX A

MARINE CLIMATOLOGY OF THE NORTHERN NORTHEAST ATLANTIC: 63°N, 2°W (OFF NORWAY)

PART I. GENERAL MARINE CLIMATOLOGY OF THE NORTHEASTERN ATLANTIC: 63°N, 2°W (OFF NORWAY) AND 58°N, 12°W (OFF SCOTLAND)

1. A general climatology for two locations in the northeast Atlantic is developed. Location A is taken to be at 63°N - 2°W and Location B at 58°N - 12°W, see Figure A-1. The two locations are considered important to U.S. Navy operations from the viewpoint of the possible occurrence of a high intensity U.S. - Soviet naval conflict in those waters. As the two open-ocean areas are only 420 nautical miles apart, distinctions will only be made between the two when a difference in the frequency of occurrence of some environmental parameter occurs. The prime data source for this general climatology is Reference 2. Some data are derived from References 3 and 4.

2. The ocean currents and the Icelandic Low are the major factors whose interaction helps determine the climatic pattern for the northeast Atlantic from Greenland to the British Isles and Norway.

Ocean Currents can provide significant influences on the climate of the surrounding area in the form of temperature, concentration and migration of ice, and the general habitability of the region. The more important North Atlantic Ocean currents have a circulation pattern which coincides to that of the prevailing winds. The mid-North Atlantic currents have a clockwise flow which parallels the westerly winds to the north and the easterly trade winds to the south. In the northern North Atlantic, which is the area of greater concern to this climatology, the circulation of the currents is counterclockwise, is centered on the polar front zone, and is influenced by the polar easterlies to the north and the westerlies to the south.

The major ocean currents of concern here are illustrated in Figure A-1. One flows to the west of the British Isles where it forms two branches: a northward drift which brings warming waters to the coast of Norway; and a secondary current which passes to the south of Iceland then turns back southward. This current develops warm characteristics in the Gulf of Mexico and near the West Indies and continues to be a relatively warm current along the south coast of Iceland and the western coasts of Norway

and the British Isles. The other important current in the northern North Atlantic flows from the northern northeast through the Denmark Straits between Greenland and Iceland and is relatively cold with characteristics acquired from the Arctic. In summary then, it is the former, warmer current which is of more importance to the two locations of interest in this climatology.

3. The Icelandic Low is the dominating pressure system influencing weather from eastern Canada across the northern Atlantic to Western Europe. The mean sea level pressure and storm tracks over the area for February (winter), May (spring), August (summer), and November (fall) are shown in Figure A-2. It is apparent that this low pressure system maintains its identity and strong influence throughout the year. Its average intensity is greatest during December and January and weakest from April through August, and it appears to move with the seasons being farther north during the summer and farther south during the winter. The southward migration in winter brings an increase in frontal activity across the area. The wind velocities and state of the sea can both be expected to be higher in the winter though some storm activity should be expected year round for both Location A and Location B. Thunderstorms may occur in winter, usually between 0300 and 1200 hours GMT, at Location A, though rarely occur in spring, summer, or fall. At Location B, thunderstorms may occur in winter between 2100 and 1200 hours GMT, in summer between 2100 and 0600 hours GMT, in fall at any time of day, and they rarely occur in spring. The most frequent occurrence of thunderstorms for either location is in the fall at Location B and is less than 0.5 percent of the time.

4. Gale force winds of 34 knots or greater occur in conjunction with the intense low pressure systems and hence become more frequent as the systems become more numerous and intense. At Location B, gales may occur 11 percent of the time in winter, 3 percent in spring, 2 percent in summer, and 8 percent in fall. During the winter 90 percent of all gales which occur last less than one day and about 50 percent of them will be followed by another in less than a day. Gales at Location A occur somewhat less frequently than at B, though when they do occur they tend to last a few hours longer and reoccur at slightly longer intervals than those at B.

5. The mean wave height accompanying these gales is 18 to 21 feet at Location A regardless of season. The mean wave height accompanying the gales at Location B varies from 11 to 24 feet where the larger mean heights tend to occur in winter, spring, and fall. The higher mean heights at Location B are apparently due to higher observed gale force wind speeds rather than the duration times of the winds themselves.

6. Generally, sea direction coincides with wind direction which, for Location A is primarily from the north-northeast or west-southwest in winter, the north-northeast in spring, the north-northeast or south-southwest in summer, and the north or south-southwest-west in fall. The predominant directions at Location B are the south-southwest-west in winter, the northeast through southwest in spring, the southwest-west in summer, and the southwest in fall. In winter and fall, at Location A, 15 to 20 percent of all observed wave heights exceed 12 feet, while in summer and spring less than 7 percent exceed 12 feet, see Figure A-3. In winter and fall, at Location B, less than 15 percent of all observed wave heights exceed 12 feet, while in spring and summer less than 3 percent exceed 12 feet. At Location A the period of the 12-foot waves tends to be 9 seconds or less while at Location B it tends to be 10 seconds or more. Periods up to 20 seconds have occasionally been observed. In winter 7 percent and in fall 4 percent of all observed waves exceed 19 feet at Location A. At Location B, slightly fewer in winter, and more in fall exceed 19 feet than at Location A. Rarely do observed waves exceed 19 feet in spring or summer. In winter and fall, waves exceeding 26 feet and with periods of 13 seconds or more can occur at either location.

7. In winter, the local wind generated seas at Location A may be accompanied by swells about 15 percent of the time, and which are generally 6 feet or less, and from the southwest. At Location B, in winter, swells are observed from a wide range of directions over 35 percent of the time and more than 18 percent of them are 9 feet or greater. In general, swells are observed throughout the year at both locations with the greatest percentage occurrence, though of perhaps lower heights, in summer.

8. The frequency of precipitation increases from a minimum during the spring and summer to a maximum in the fall and winter. Frozen precipitation is rare during the spring and summer. Liquid precipitation may occur

in any month. Ignoring precipitation type, slight intensities or rates of fall are generally twice as likely as moderate to heavy intensities. Considering drizzle and rain, slight intensities or rates are more likely regardless of season, while when considering showers and thunderstorms, the rate tends to be moderate to heavy. On an annual basis, the overall amount of precipitation is similar for both locations and never exceeds 19 percent frequency of occurrence.

9. The oceanographic area between Iceland and Scotland has sufficient vertical mixing associated with the prevailing winds to permit relatively little fog. The frequency of occurrence at Location A ranges from 3 percent in winter to 10 percent in summer when it is usually accompanied by a south to south-easterly wind and seas of 5 feet or less. Similar fog occurrences exist for Station B but with a somewhat less percent frequency of occurrence.

10. The daily mean temperatures for Location A range from 40°F in winter to about 50°F in summer, while at Location B the monthly means are up to 5 degrees higher than at Location A. During the winter, subfreezing temperatures, accompanied by gale force winds have a 2 percent frequency of occurrence at Location A and less than 1 percent at Location B, while the percentage frequency of potential moderate* superstructure icing is less than 1 percent at Location A and virtually nonexistent at Location B. Severe** superstructure icing is not expected to occur at any time during the year at either location.

11. Icebergs have never been observed at either Location A or Location B, however, two bergs were sighted southeast of the Faeroe Islands and west of the Shetland Islands in the winter of 1836, and a large piece of ice was sighted to the west of the Shetland Islands in the fall of 1927.

12. The sea surface temperature has a mean value of 45°F in winter and 52°F in summer at Location A and is several degrees higher at Location B.

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*Moderate here means a buildup of less than one-tenth of an inch per hour and is derived from observations with temperature less than or equal to 28°F and wind speed greater than or equal to 13 knots.

**Severe here means a buildup of one-tenth of an inch or more per hour and is derived from observations when temperature is less than or equal to 16°F and wind speed is greater than or equal to 30 knots.

In winter the sea surface temperature rarely exceeds 50°F at Location A and 56°F at Location B. In summer, 60°F is rarely exceeded at Location A and 65°F is rarely exceeded at B. The relative humidity at Location A has a daily mean value of about 85 percent in winter, 86 percent in spring, 88 percent in summer, and 82 percent in fall. The daily means at Location B are 3 to 5 percent less than at Location A. Fifty percent of all observed mean sea level pressures at Location A are less than 1007.5 millibars in winter, 1015 millibars in spring, 1010 millibars in summer, and 1005 millibars in fall, see Figure A-2. At Location B, the mean sea level pressure is somewhat higher than at Location A in all but the spring when it is slightly lower.

13. During the winter, the observed average visibility percent frequency of occurrence at Location A is 20 percent for less than 5 nautical miles, 6 percent for less than 2 nautical miles, and 2 percent for less than 1/2 nautical mile. The percentage visibilities at Location B are up to 1/2 the values at Location A. In general, visibility is somewhat improved in summer, however, low visibility, e.g., less than 50 yards, occurs jointly with a low ceiling height, e.g., less than 150 feet, in 13 percent of observations at Location A and 3 percent at Location B. Irrespective of season, periods of visibility of less than 2 nautical miles rarely exceed one day.

14. The maximum number of hours of daylight occurs in June when the sun is above the horizon about 20 hours at Location A and 18 hours at Location B. The minimum number of hours of daylight, 5 hours at Location A and 6½ at Location B, occurs in late December and early January.

The water depth at Location A is about 1000 fathoms and rises to 500 fathoms to the south. The water depth at Location B is also 1000 fathoms and rises to 500 fathoms to the east.

15. In summary, a general climatology for Locations A and B is developed with the emphasis being placed on the winter season which is considered the most severe from the viewpoint of operations of naval surface combatants. The overall climatologies of the two identified locations are rather similar with some differences in percentage occurrences of certain environmental parameters. For example, at Location A, one might expect fewer thunderstorms, fewer occurrences but longer time durations of gale force

winds, more concentrated prevailing winds and corresponding wave directions, higher though generally shorter (lower period) waves, more frequent occurrence of swell, colder surface and atmospheric temperatures, more solid precipitation, and lower overall visibility.

Ⓐ 63° N , 2° W
Ⓑ 58° N , 12° W

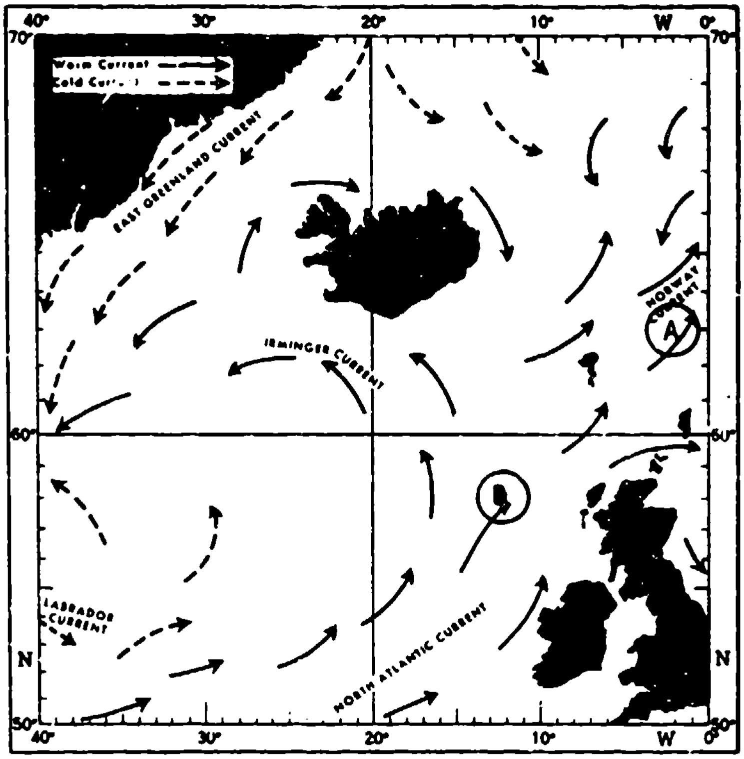
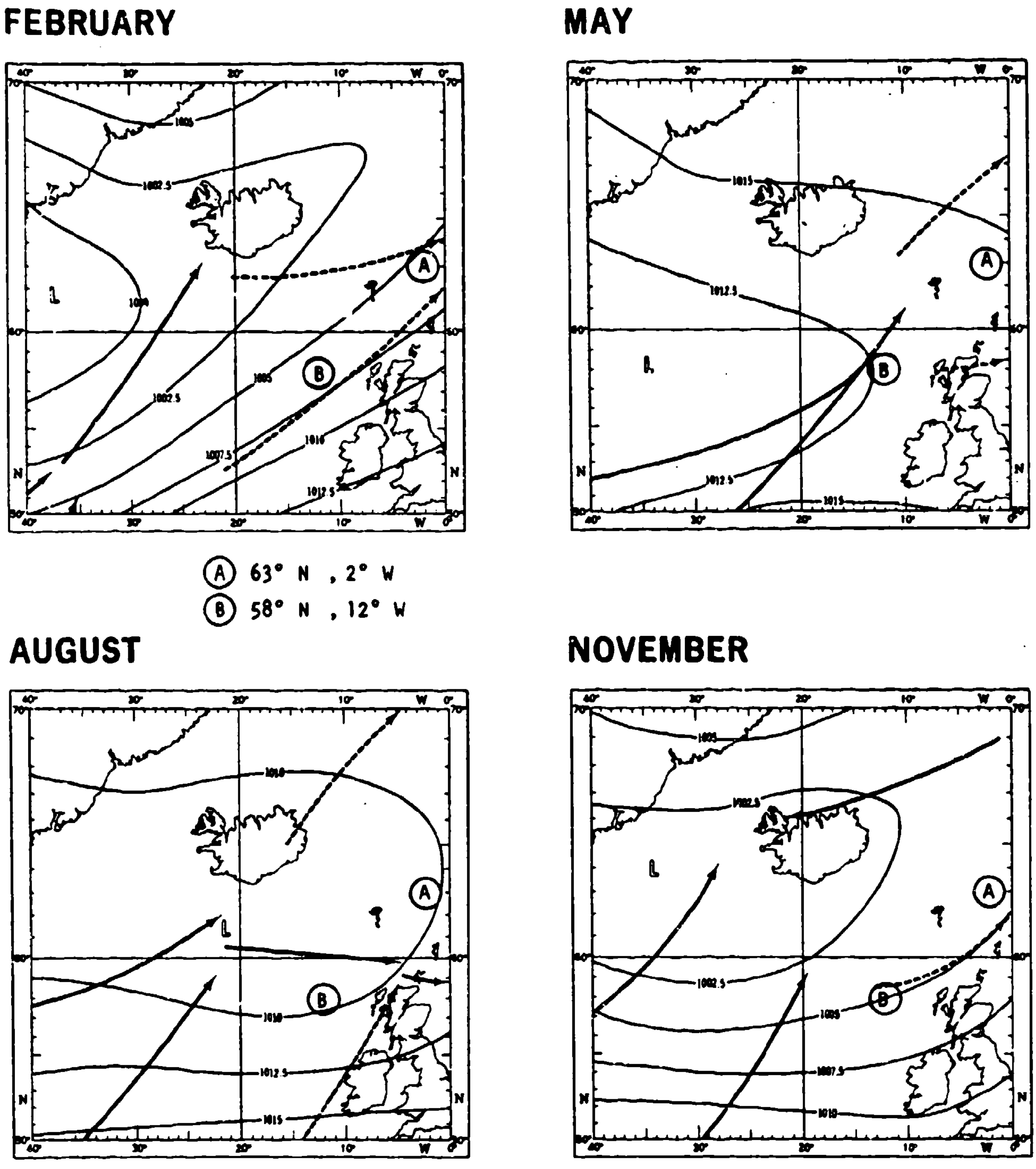


Figure A-1 - Generalized Ocean Currents for the Northeastern North Atlantic



—— Mean Sea Level Pressure in Millibars

——▶ Primary track, along which there has been maximum concentration of individual storm center paths

- - - -▶ Secondary track, along which there has been moderate concentration of individual storm center paths

Figure A-2 - Seasonal Mean Sea Level Pressures and Storm Tracks

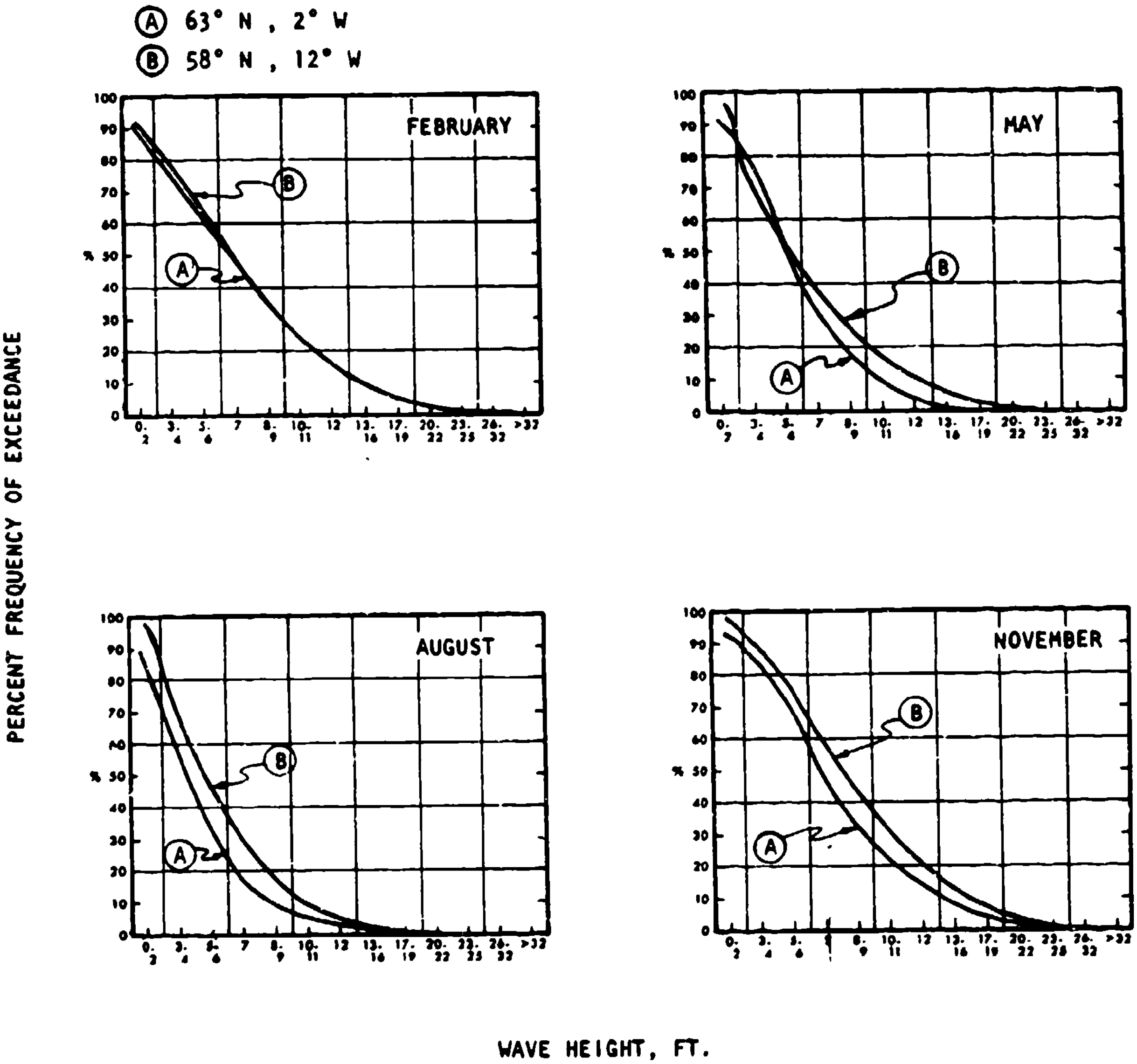


Figure A-3 - Seasonal Wave Height Exceedances for the Northeastern North Atlantic

PART II. WINTER (FEBRUARY) CLIMATOLOGY OF THE NORTHERN NORTHEAST ATLANTIC: 63° N, 2° W (OFF NORWAY)

The following data graphs are derived primarily from Reference 2 for the worst wind/wave season, February. Figure A-11a is adopted from Reference 3.

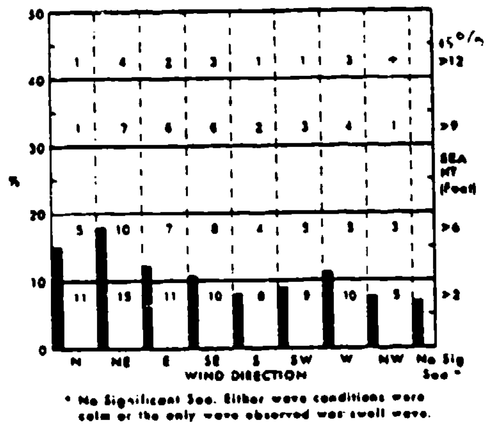


Figure A-1a - Sea Height by Wind Direction

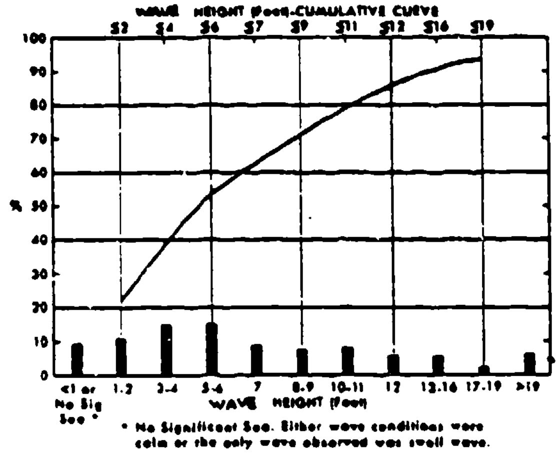


Figure A-1b - Sea Height - Cumulative Distribution

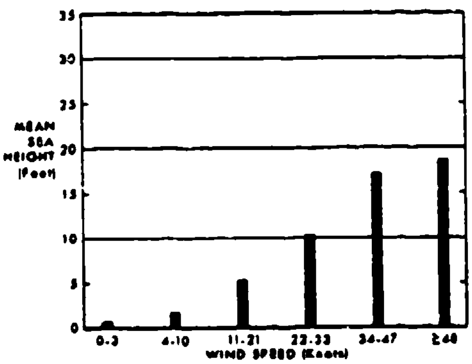


Figure A-1c - Mean Sea Height by Wind Speed

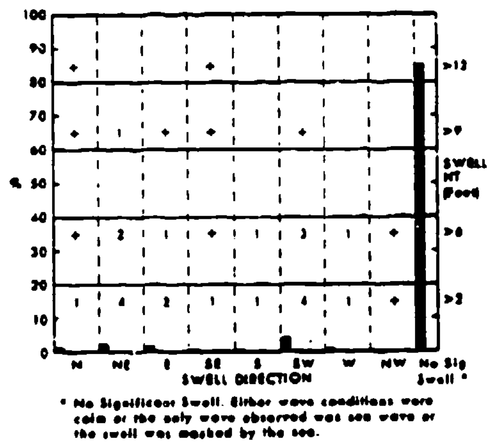
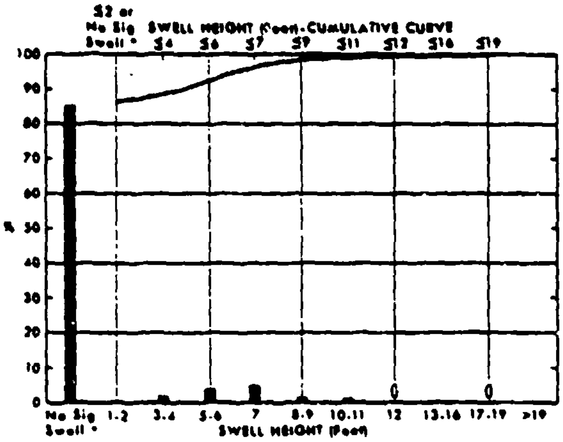


Figure A-1d - Swell Height by Direction



* No Significant Swell. Either wave conditions were calm or the only wave observed was sea wave or the swell was masked by the sea.

Figure A-1e - Swell Height - Cumulative Distribution

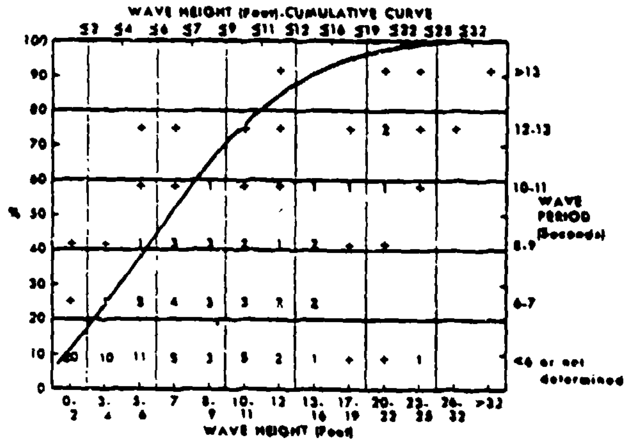


Figure A-1f - Wave Height and Period

RETURN PERIOD (YEARS)	MAXIMUM SIGNIFICANT WAVE (FEET)	EXTREME WAVE (FEET)
5	44	78
10	49	89
25	58	104
50	65	117
100	73	131

Figure A-1g - Return Periods for High Waves

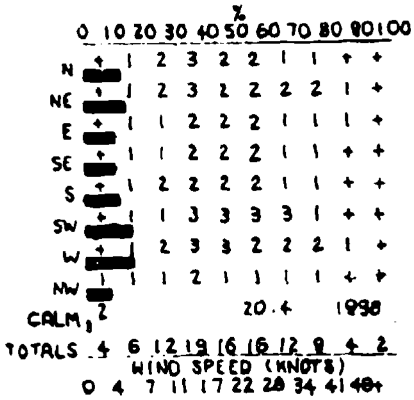


Figure A-2a - Wind Speed by Direction

RETURN PERIOD (YEARS)	MAXIMUM SUSTAINED WIND (KNOTS)
5	75
10	81
25	91
50	98
100	107

Figure A-2b - Return Periods for Maximum Sustained Winds

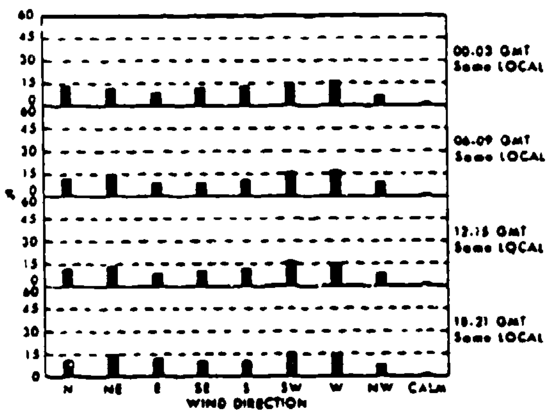


Figure A-2c - Wind Direction - Diurnal Variations

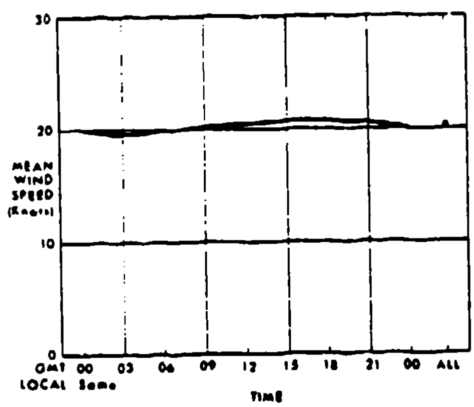


Figure A-2d - Wind Speed - Diurnal Variation

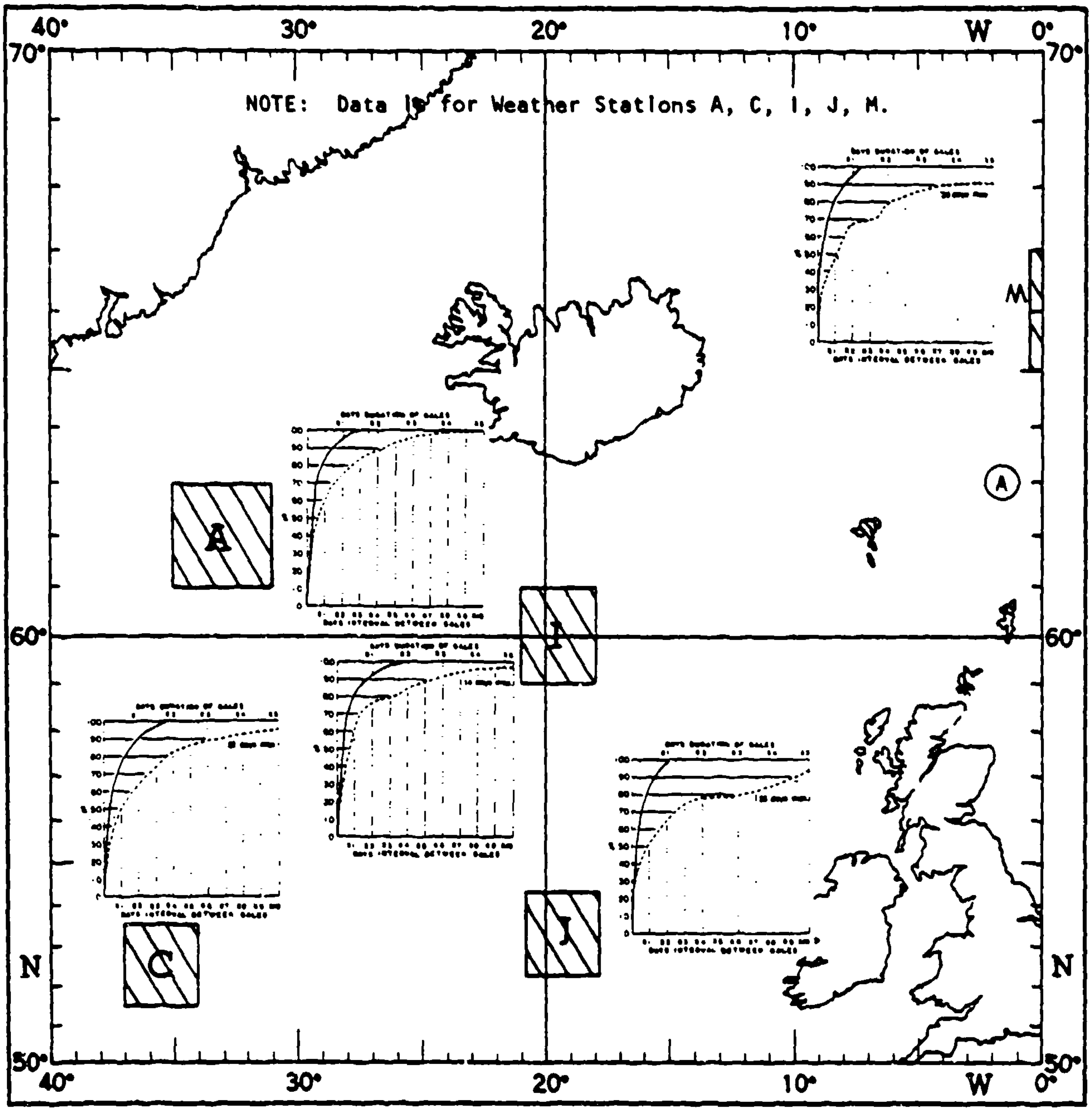


Figure A-2e - Gale Persistence

NOT AVAILABLE

Figure A-2f - Wind Speed
Diurnal Variation

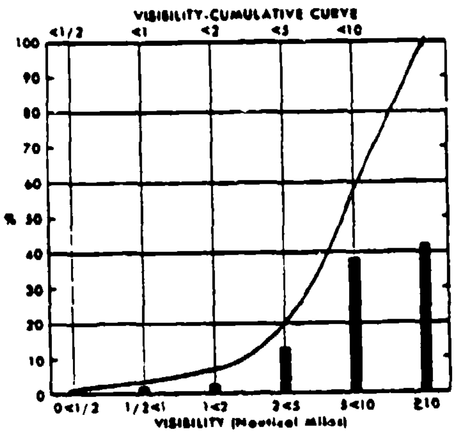


Figure A-3a - Visibility - Cumulative Distribution

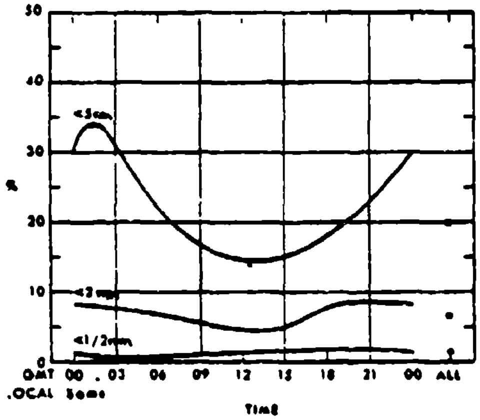


Figure A-3b - Visibility - Diurnal Variation

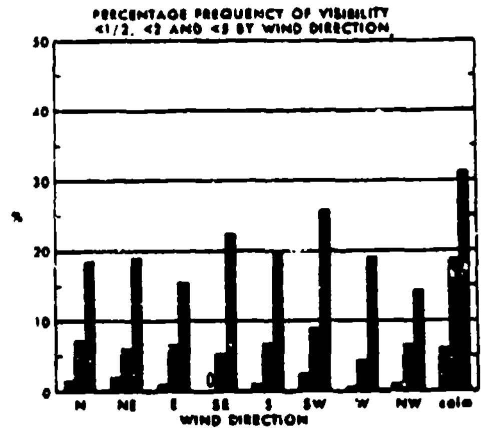


Figure A-3c - Visibility by Wind Direction

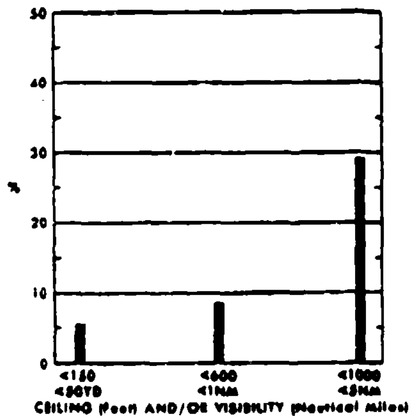


Figure A-3d - Low Visibility and/or Ceiling Height

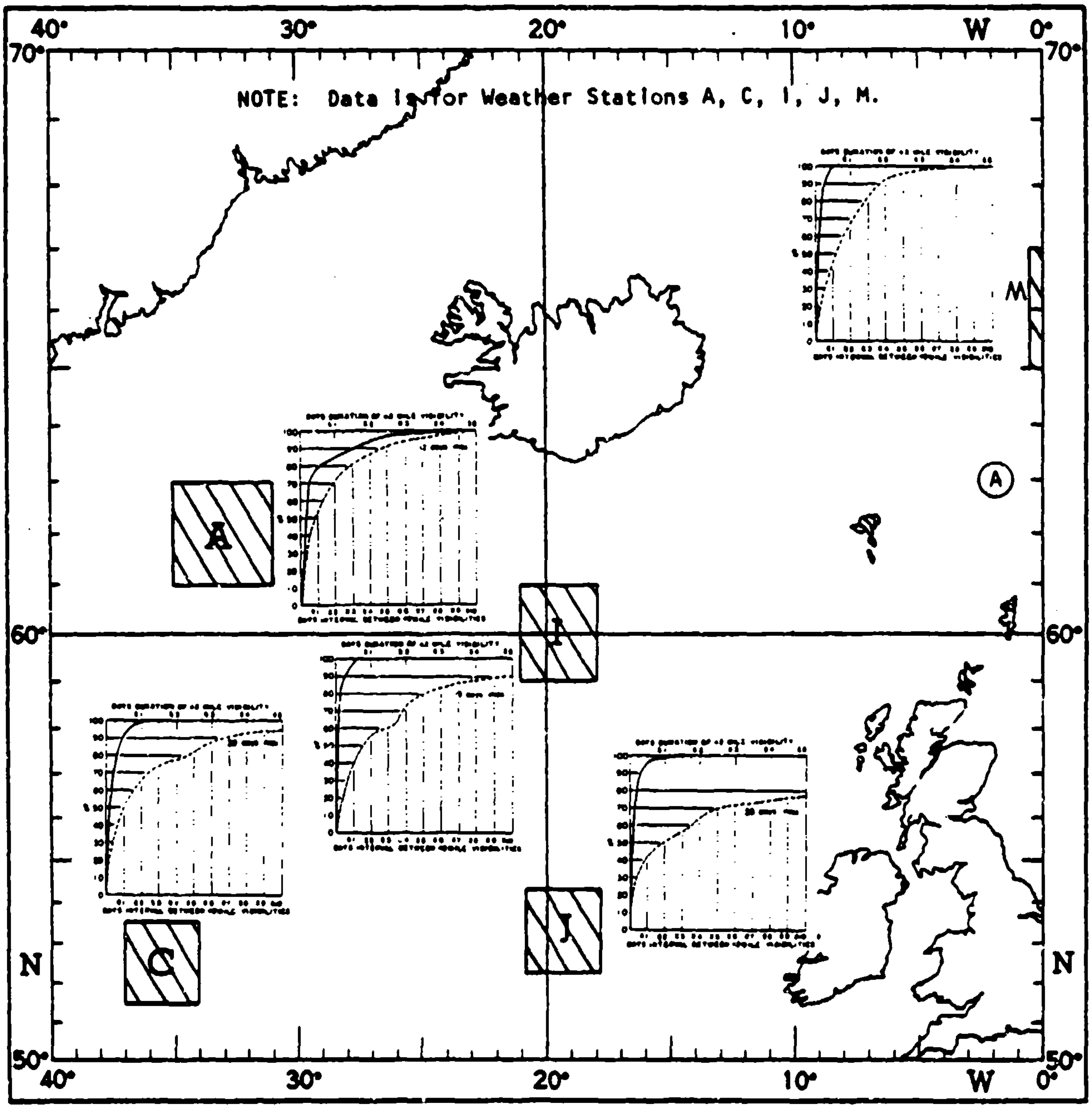


Figure A-3e - Visibility Persistence

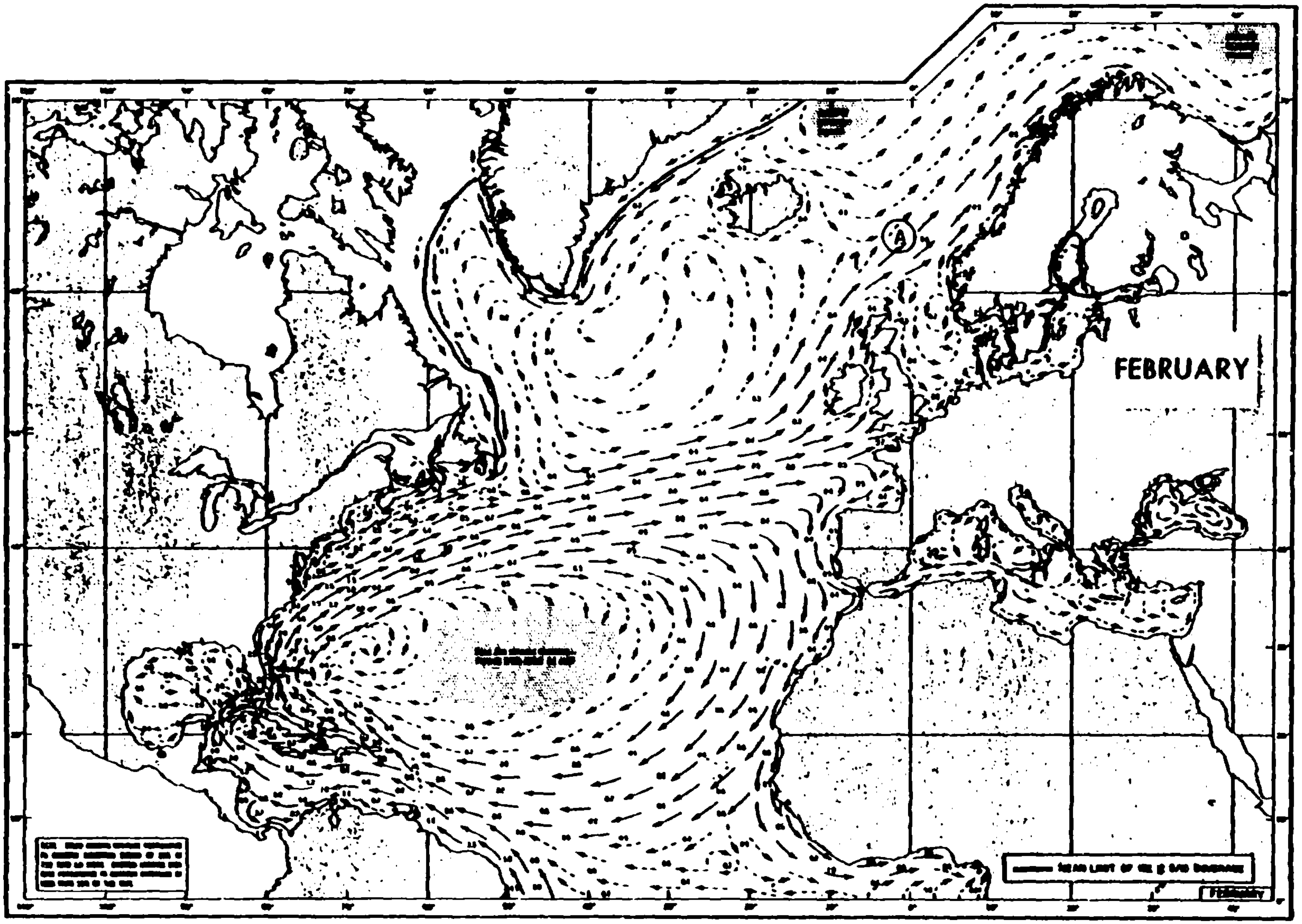


Figure A-4a - Mean Surface Current Speeds and Prevailing Directions

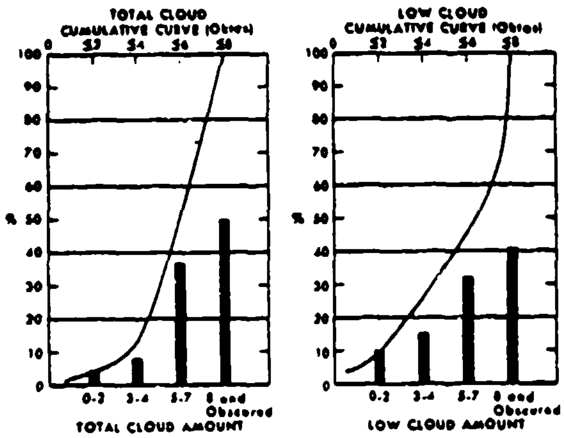


Figure A-5a - Cloud Amounts - Cumulative Distribution

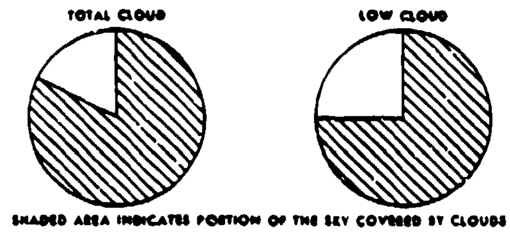


Figure A-5b - Mean Cloud Amounts

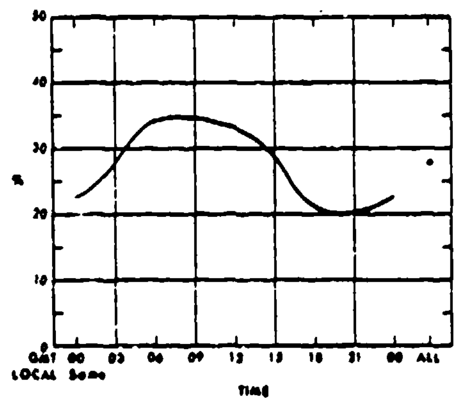


Figure A-5c - Good Cloud Conditions - Diurnal Variation

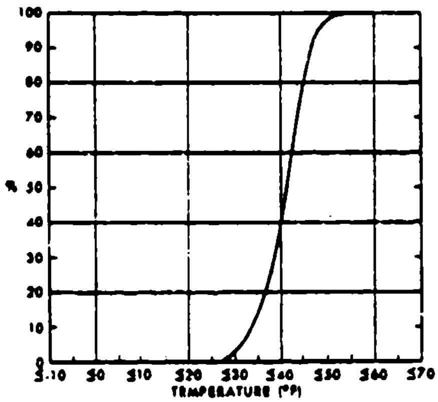


Figure A-6a - Air Temperature - Cumulative Distribution

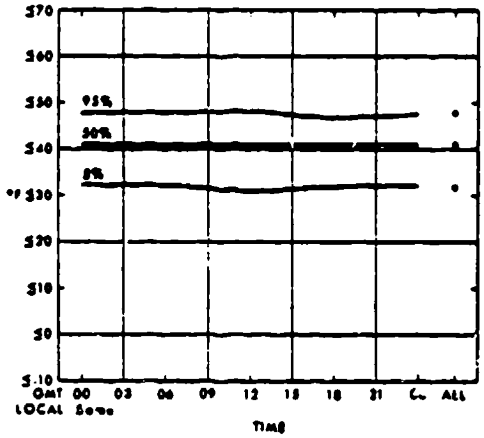


Figure A-6b - Air Temperature - Diurnal Variation

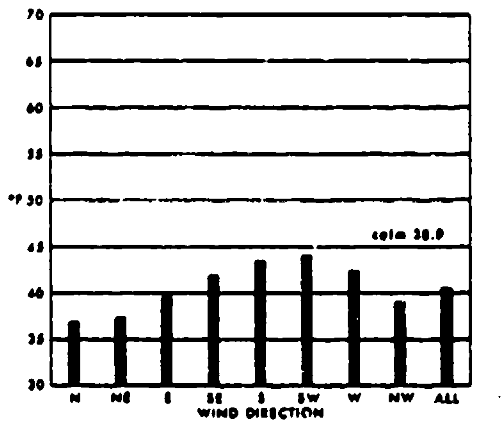


Figure A-6c - Mean Air Temperature by Wind Direction

PERCENTAGE FREQUENCY OF SUB-FREEZING TEMPERATURES

WIND SPEED	FEB	MAY	AUG	NOV
22-33	3.0	0.5	0.0	1.4
≥34	1.9	0.0	0.0	0.7

Figure A-6d - Air Temperature and Gales

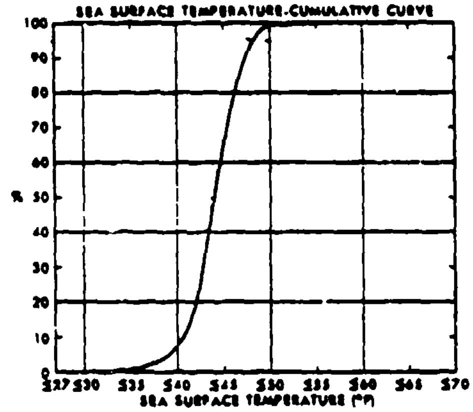


Figure A-6e - Sea Surface Temperature

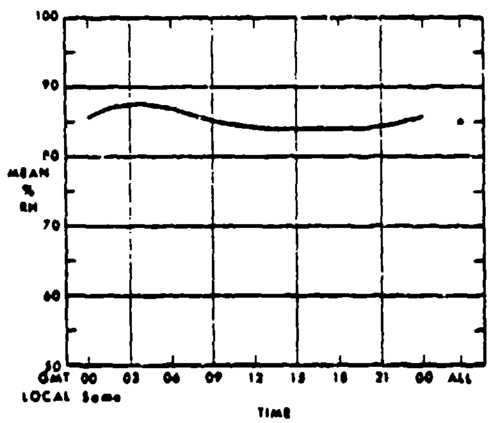


Figure A-6f - Relative Humidity - Diurnal Variation

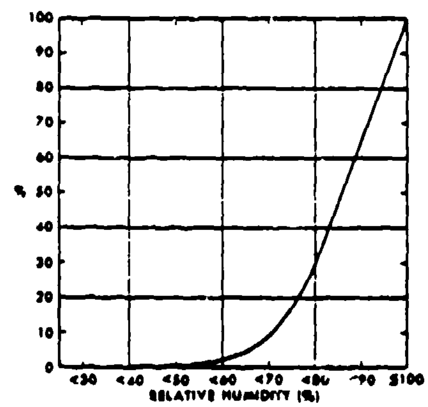


Figure A-6g - Relative Humidity - Cumulative Distribution

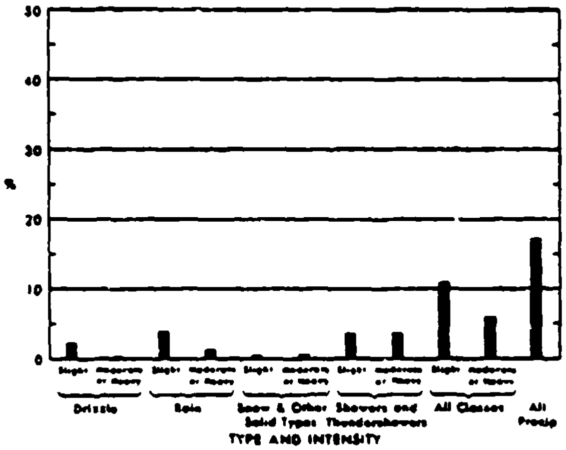


Figure A-7a - Precipitation
by Type

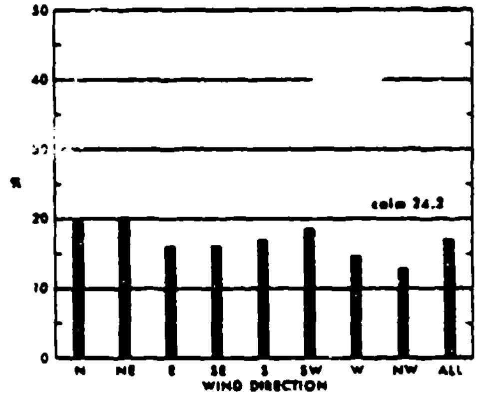


Figure A-7b - Precipitation
by Wind Direction

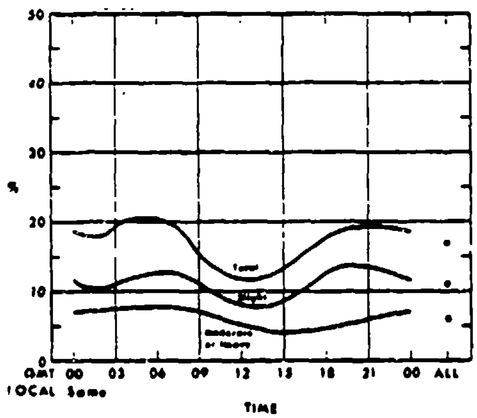


Figure A-7c - Precipitation -
Diurnal Variation

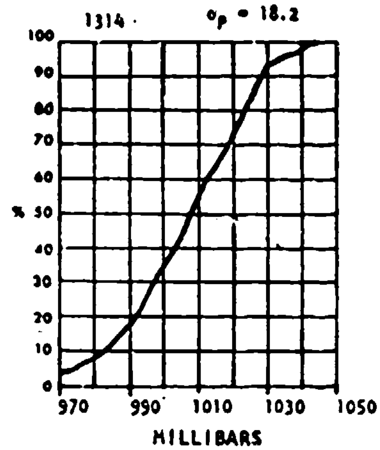


Figure A-8a - Sea Level Pressure - Cumulative Distribution

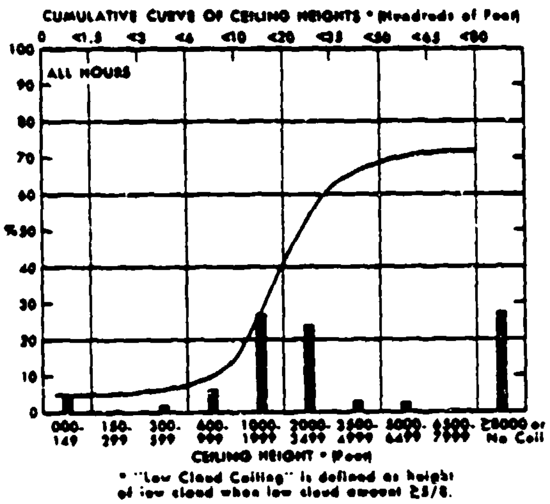


Figure A-9a - Ceiling Height

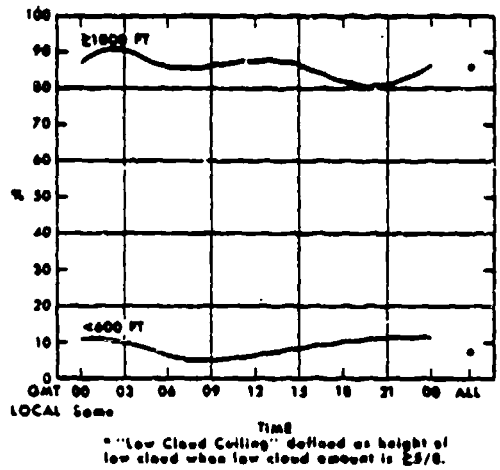


Figure A-9b - Ceiling Height - Diurnal Variation

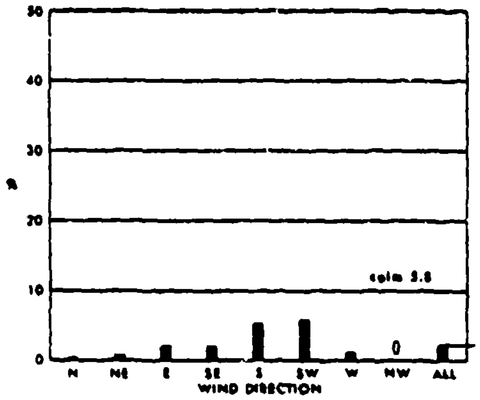


Figure A-10a - Fog versus
Wind Direction

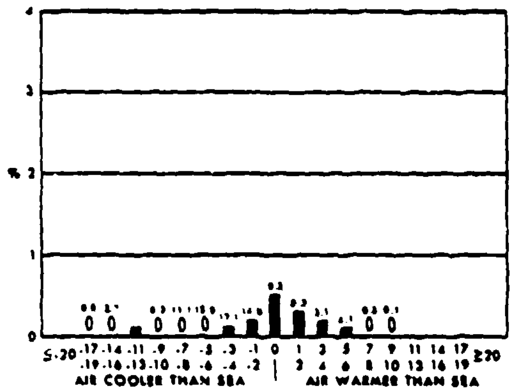


Figure A-10b - Fog versus
Air - Sea Temperature Difference

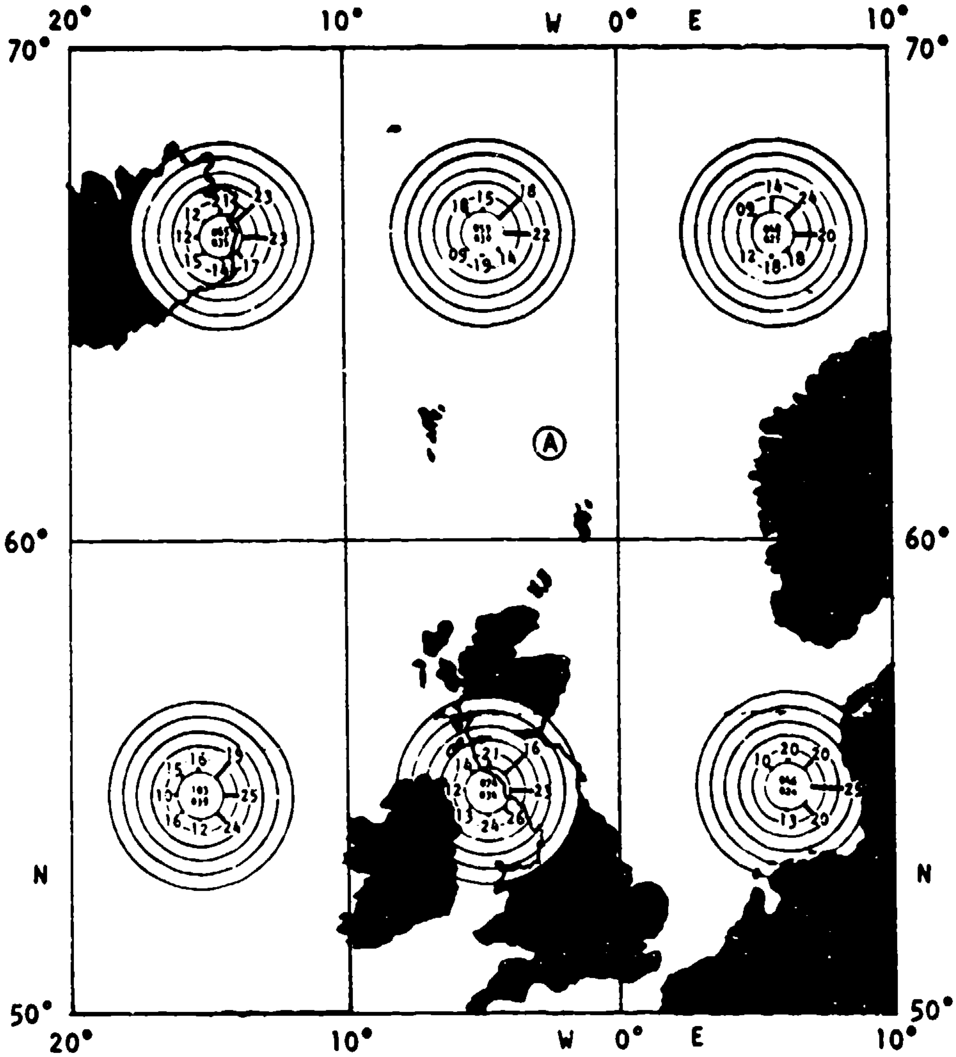


Figure A-11a - Low Pressure Centers

NO OCCURRENCES
REPORTED

Figure A-11b - Extratropical Cyclones

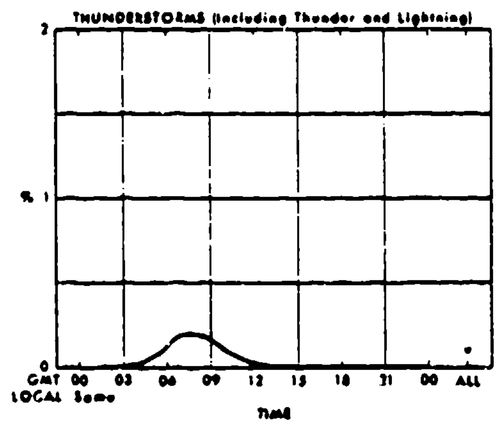


Figure A-11c - Thunderstorms

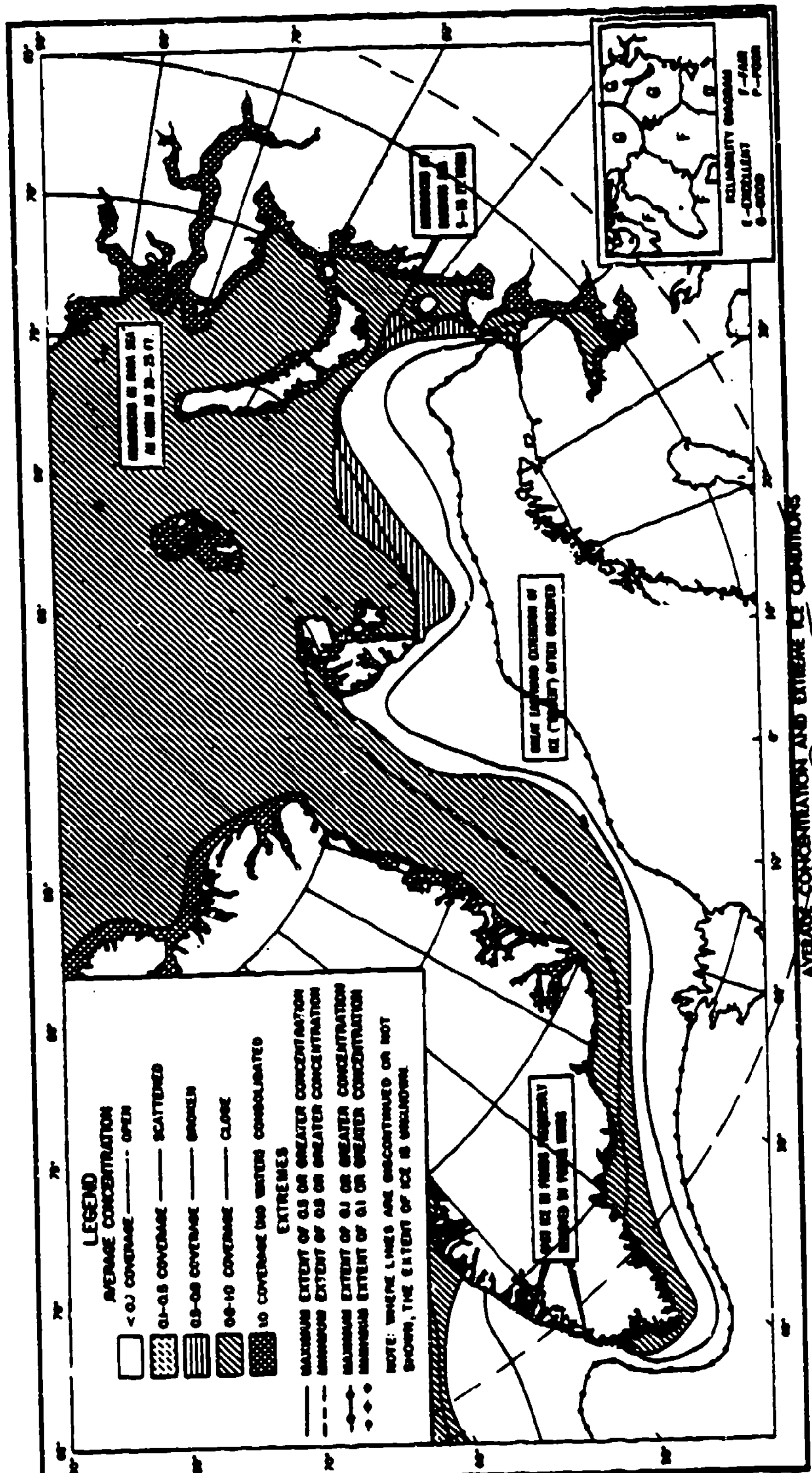


Figure A-12a - Concentration

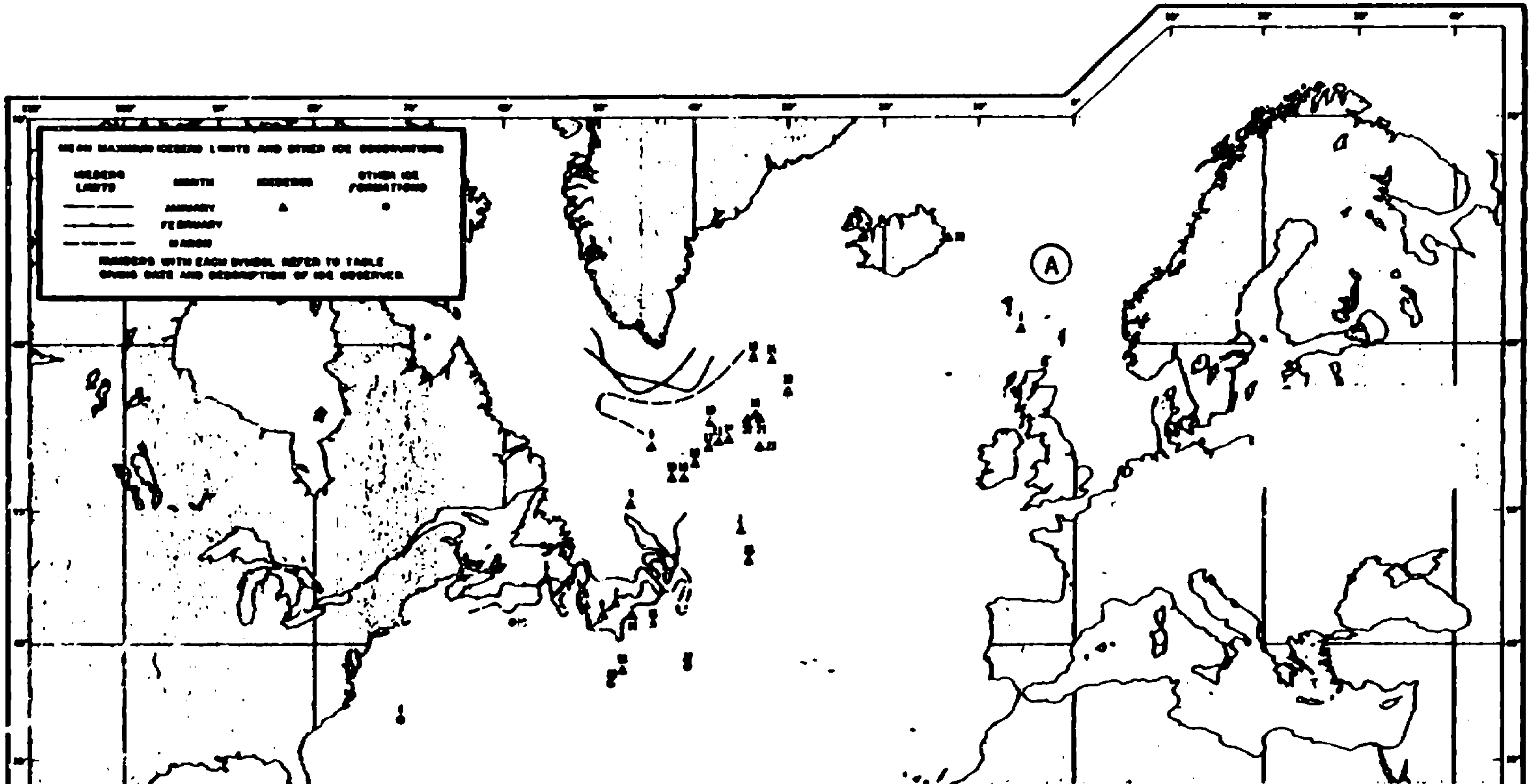


TABLE OF OTHER OBSERVATIONS OF ICE

JANUARY

No.	Date		Description
1	Jan.	[illegible]	2 bergs
2		1913	berg: [illegible]' long, 60' high
3		1913	berg
4		[illegible]	hummock: 30' around, 3' high
5		[illegible]	berg
6		[illegible]	berg
7		[illegible]	berg
8		[illegible]	small berg
9		[illegible]	berg or piece of ice
10		[illegible]	berg
11		[illegible]	berg
12		[illegible]	berg
13		[illegible]	berg

FEBRUARY

No.	Date		Description
14	Feb.	1914	berg
15		1914	berg
16		[illegible]	piece of ice damaged bow of SS [illegible]
17		[illegible]	berg
18		[illegible]	berg
19		[illegible]	large berg
20		[illegible]	large berg and 2 growlers
21		[illegible]	small berg
22		[illegible]	small berg and several growlers
23		[illegible]	large berg
24		[illegible]	large berg

MARCH

No.	Date		Description
25	Mar.	1913	berg: [illegible]' long, [illegible]' high
26		[illegible]	piece of ice: [illegible]' long, [illegible]' high
27		1920	piece of ice: 30' long, 3' high
28		[illegible]	berg
29		[illegible]	2 bergs
30		[illegible]	berg
31		[illegible]	large berg and 10 growlers within an area 10 miles wide

Figure A-12b - Icebergs

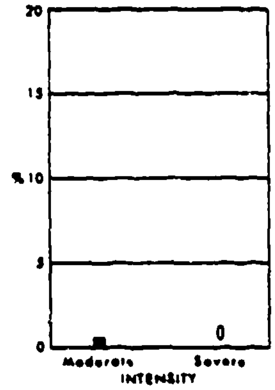


Figure A-13a - Percentage frequency of moderate and severe potential for superstructure icing

APPENDIX B

MARINE CLIMATOLOGY OF THE NORTHERN NORTH ATLANTIC:

58°N, 12°W (OFF SCOTLAND)

PART I. GENERAL MARINE CLIMATOLOGY OF THE NORTHERN NORTH ATLANTIC: 58° N, 12°W (OFF SCOTLAND)

See Appendix A, page A-2.

PART II. WINTER (FEBRUARY) CLIMATOLOGY OF THE NORTHERN NORTH ATLANTIC: 58° N, 12°W (OFF SCOTLAND)

The following data graphs are derived primarily from Reference 2 for the worst wind/wave season, February. Figure B-11a is adopted from Reference 3.

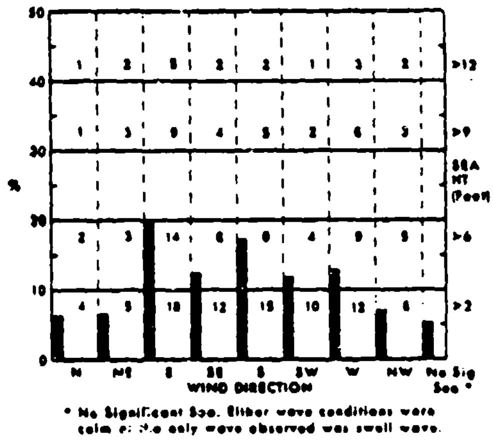


Figure B-1a - Sea Height by Wind Direction

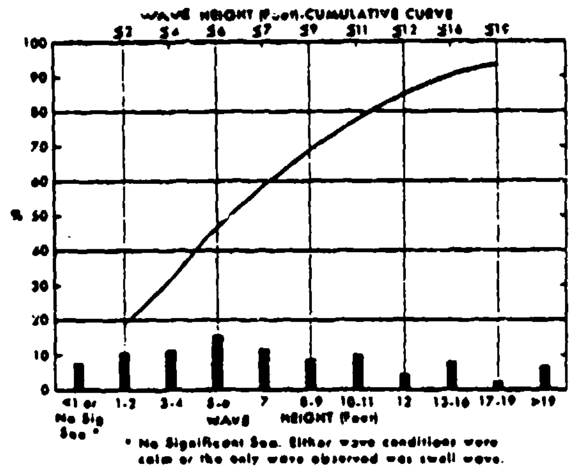


Figure B-1b - Sea Height - Cumulative Distribution

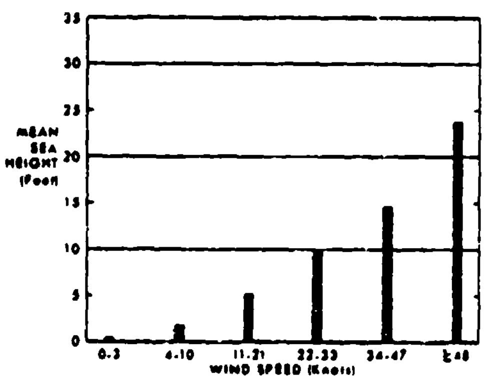


Figure B-1c - Mean Sea Height by Wind Speed

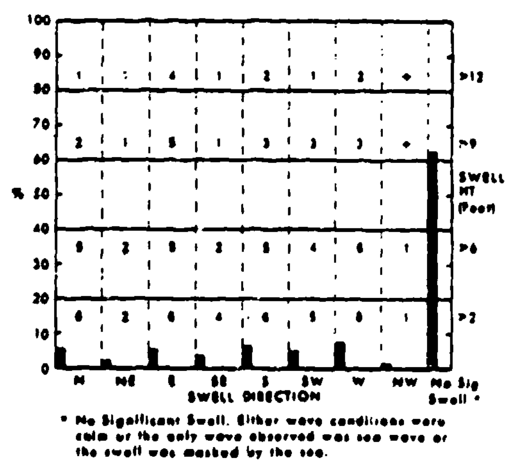
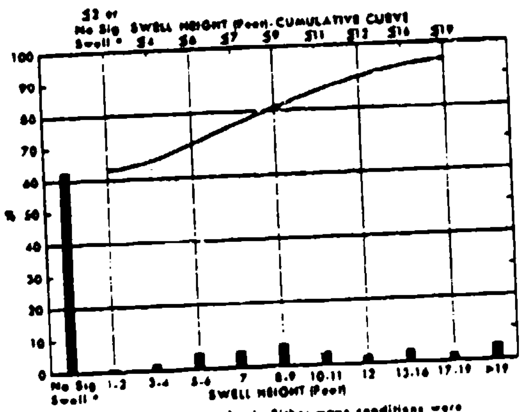


Figure B-1d - Swell Height by Direction



* No Significant Swell. Either wave conditions were calm or the only wave observed was sea wave or the swell was masked by the sea.

Figure B-1e - Swell Height - Cumulative Distribution

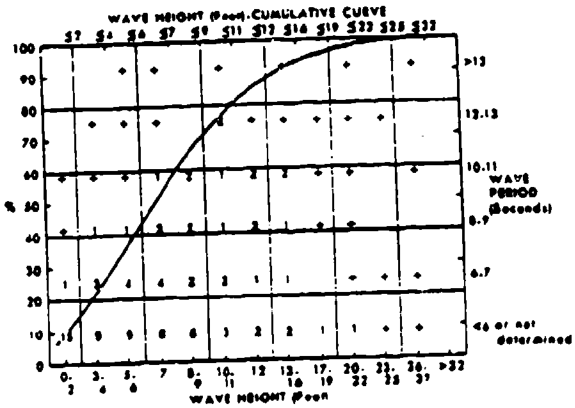


Figure B-1f - Wave Height and Period

RETURN PERIOD (YEARS)	MAXIMUM SIGNIFICANT WAVE (FEET)	EXTREME WAVE (FEET)
5	46	83
10	52	94
25	61	110
50	69	124
100	77	139

Figure B-1g - Peturn Periods for High Waves

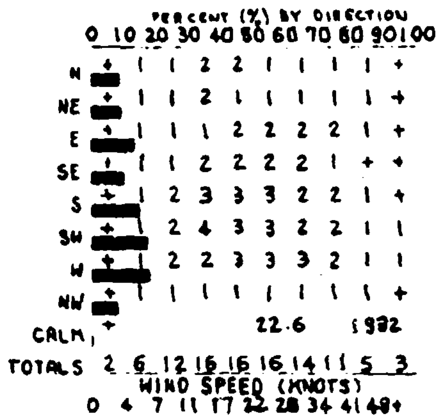


Figure B-2a - Wind Speed by Direction

RETURN PERIOD (YEARS)	MAXIMUM SUSTAINED WIND (KNOTS)
5	79
10	86
25	96
50	104
100	113

Figure B-2b - Return Periods for Maximum Sustained Winds

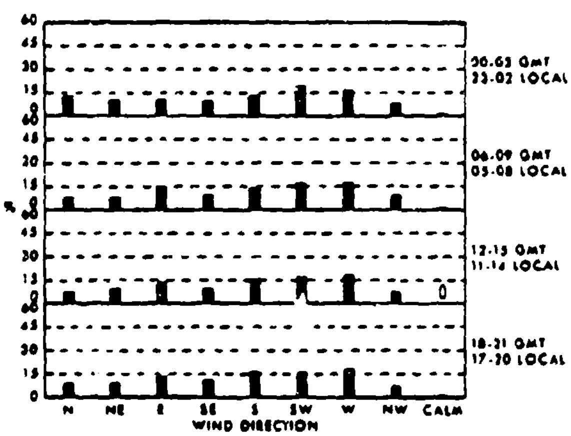


Figure B-2c - Wind Direction - Diurnal Variations

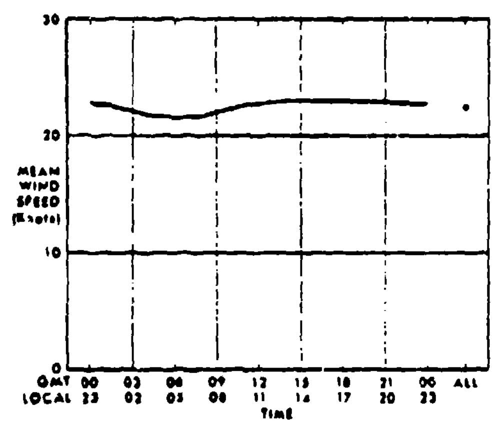


Figure B-2d - Wind Speed - Diurnal Variation

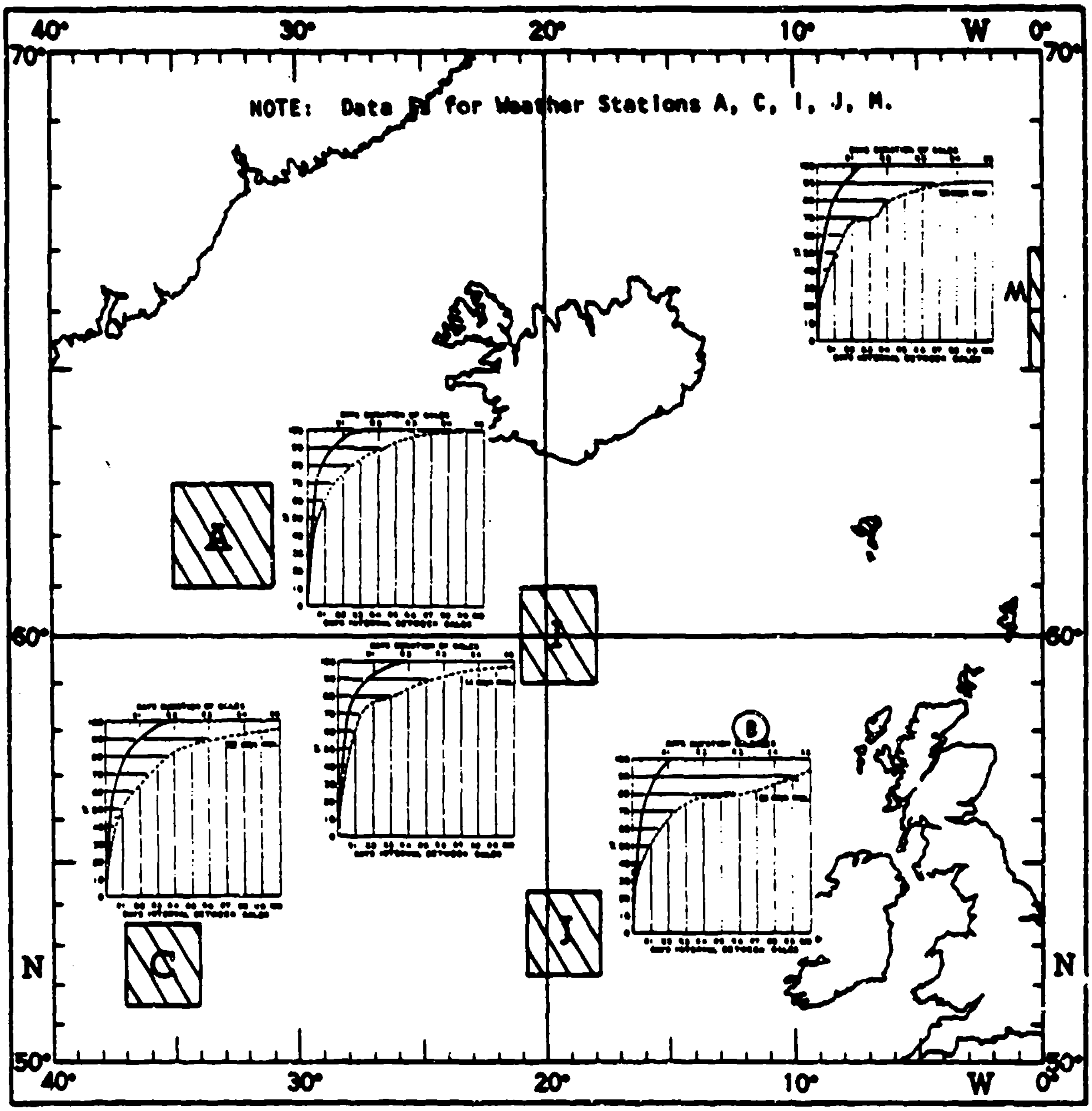


Figure B-2e - Gale Persistence

NOT AVAILABLE

Figure B-2f - Wind Speed
Diurnal Variation

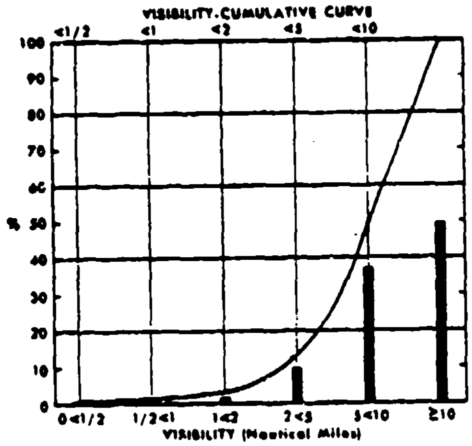


Figure B-3a - Visibility - Cumulative Distribution

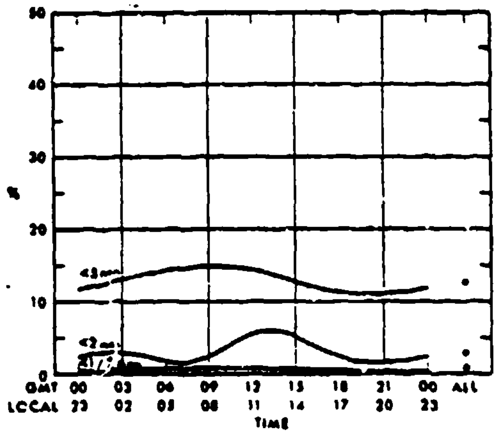


Figure B-3b - Visibility - Diurnal Variation

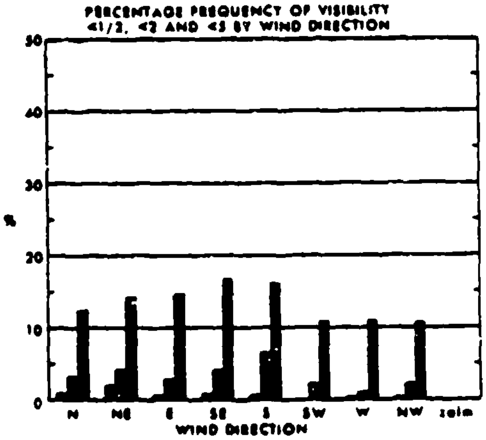


Figure B-3c - Visibility by Wind Direction

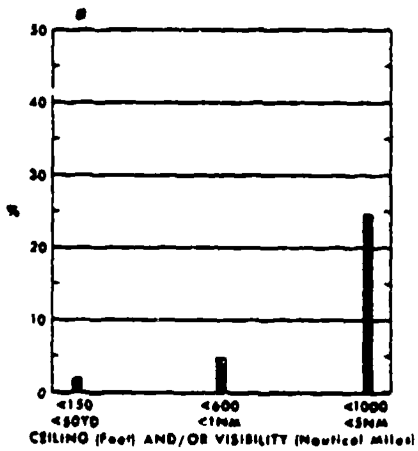


Figure B-3d - Low Visibility and/or Ceiling Height

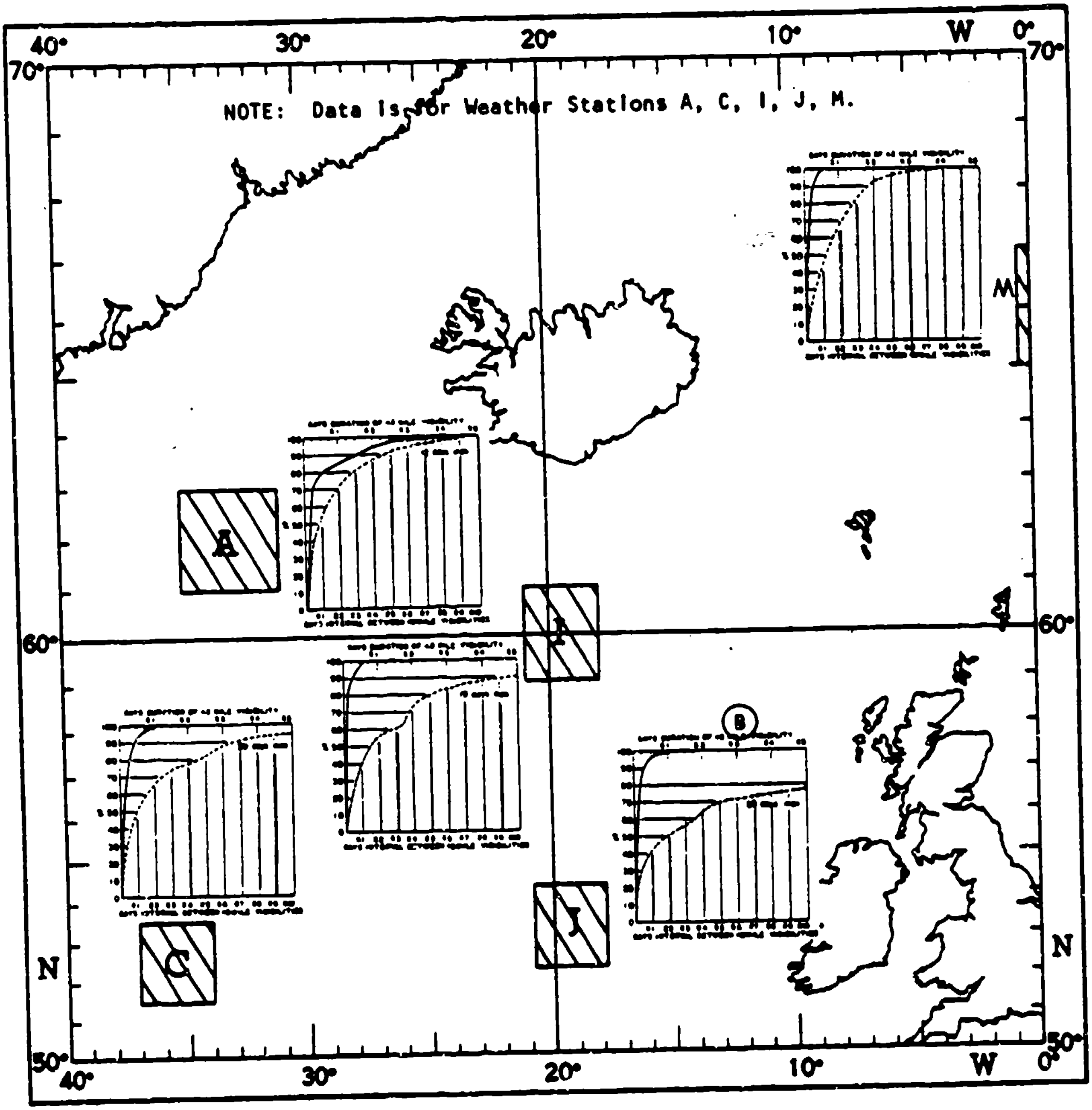


Figure B-3e - Visibility Persistence

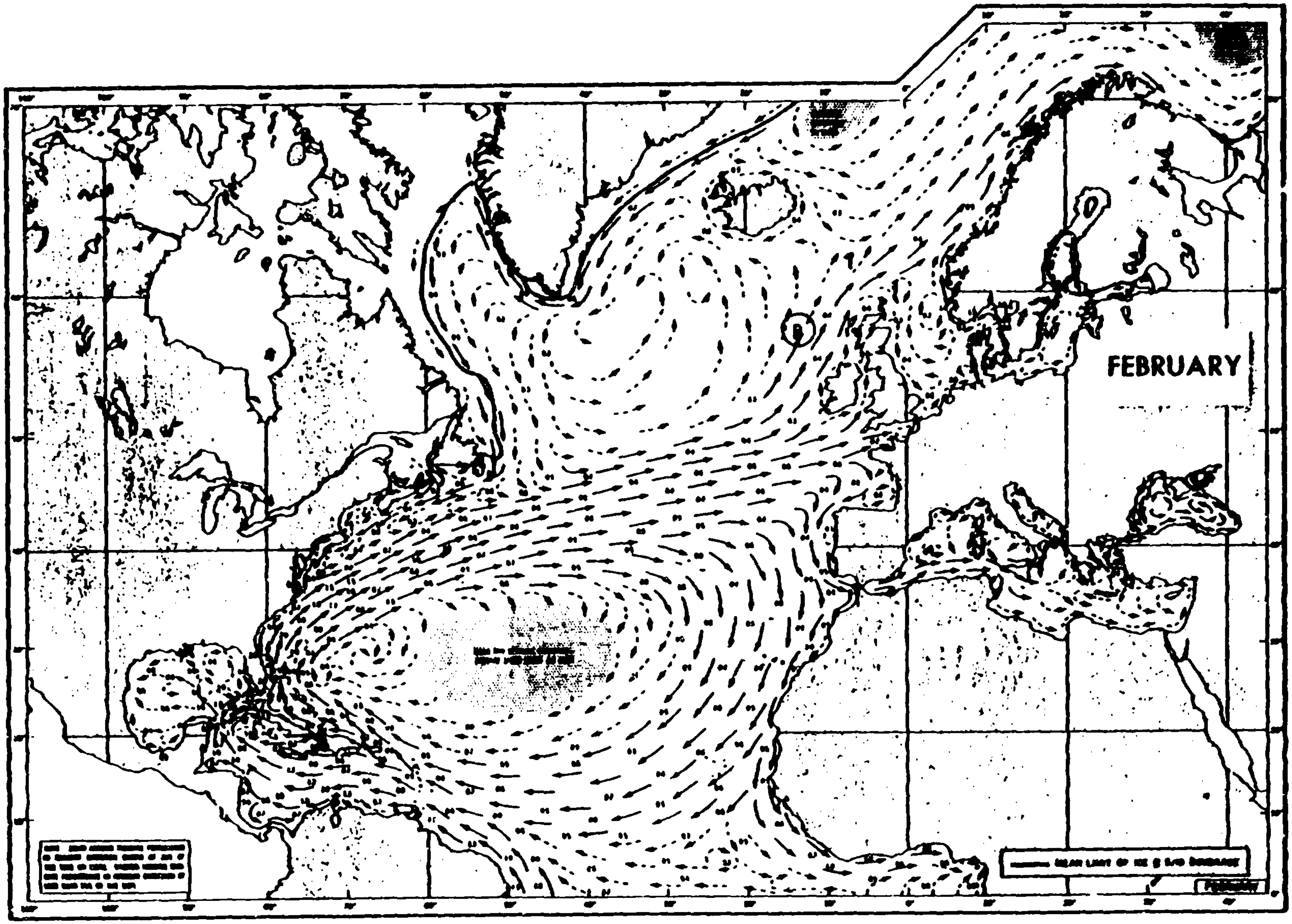


Figure B-4a - Mean Surface Current Speeds and Prevailing Directions

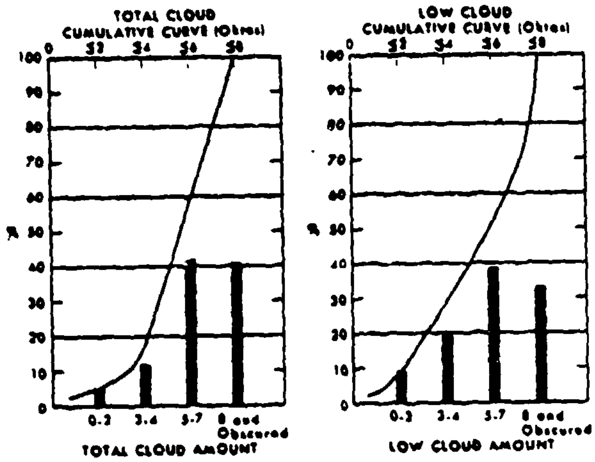


Figure B-5a - Cloud Amounts - Cumulative Distribution

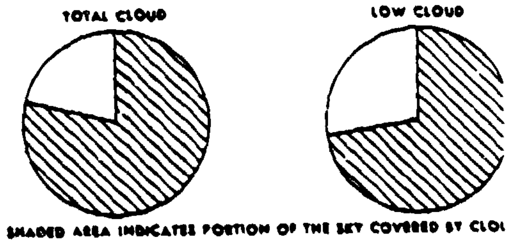


Figure B-5b - Mean Cloud Amounts

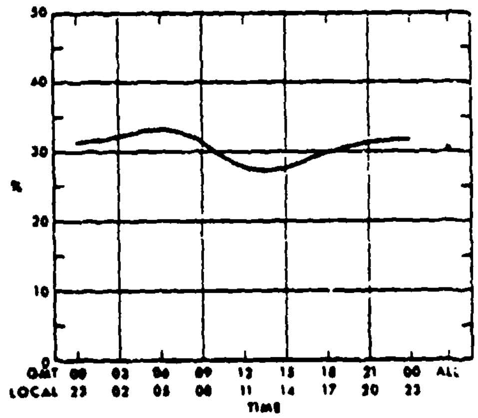


Figure B-5c - Good Cloud Conditions - Diurnal Variation

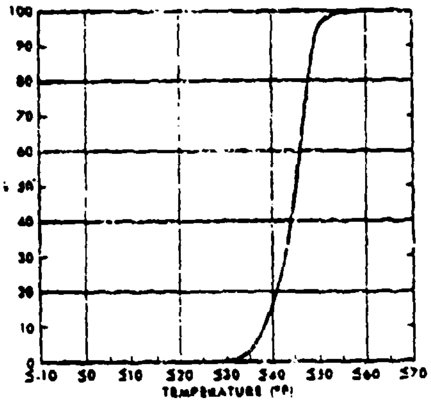


Figure B6a - Air Temperature - Cumulative Distribution

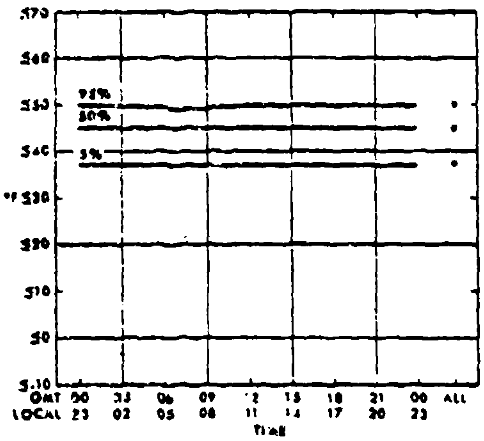


Figure B-6b - Air Temperature - Diurnal Variation

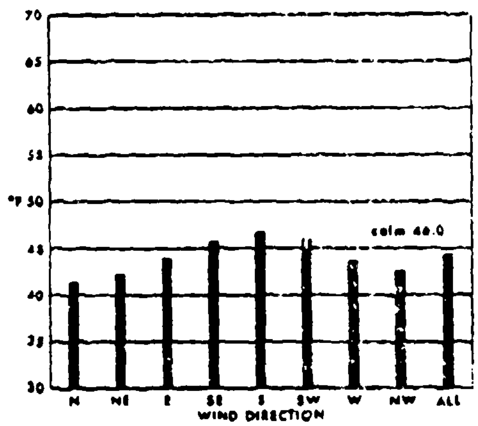


Figure B-6c - Mean Air Temperature by Wind Direction

PERCENTAGE FREQUENCY OF
SUB-FREEZING TEMPERATURES

WIND SPEED	FEB	MAY	AUG	NOV
22-33	0.4	0.0	0.0	0.3
≥34	0.7	0.0	0.0	0.1

Figure B-6d - Air Temperature and Gales

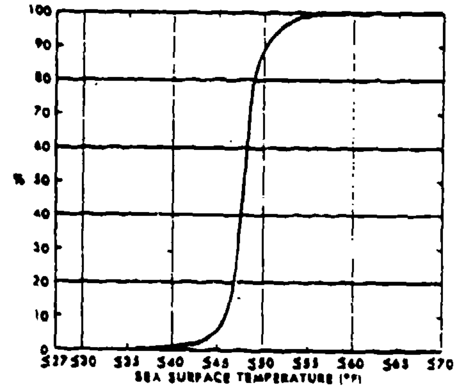


Figure B-6e - Sea Surface Temperature

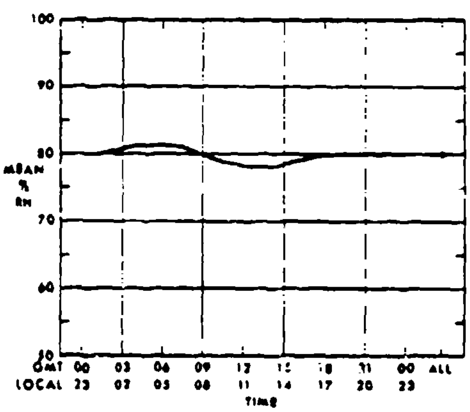


Figure B-6f - Relative Humidity - Diurnal Variation

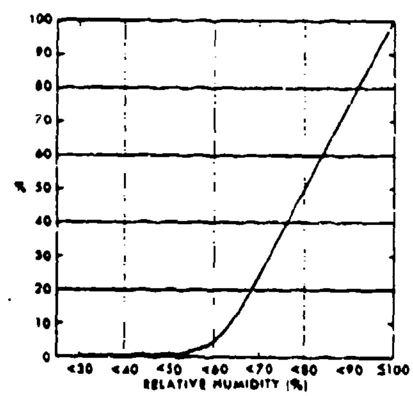


Figure B-6g - Relative Humidity - Cumulative Distribution

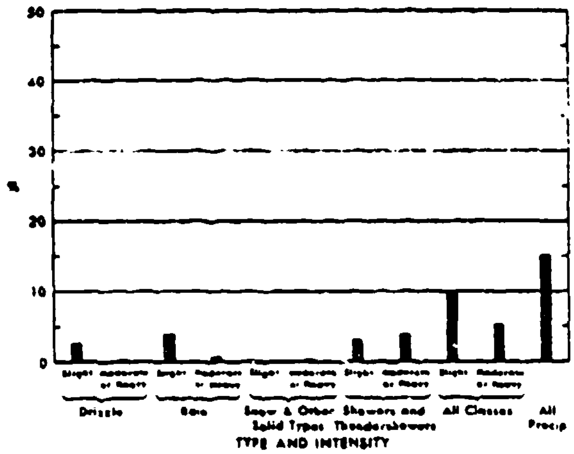


Figure B-7a - Precipitation by Type

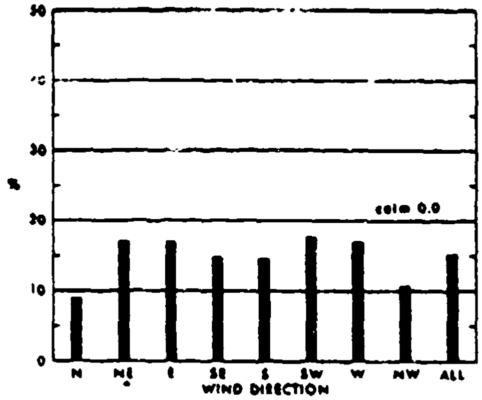


Figure B-7b - Precipitation by Wind Direction

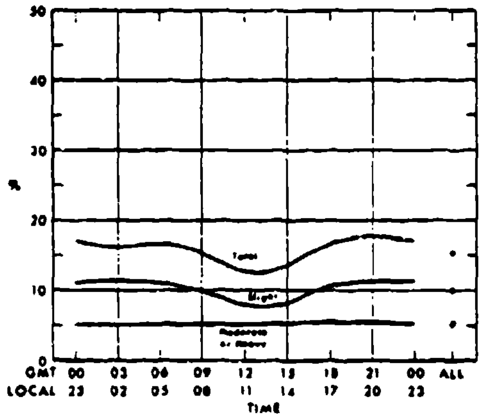


Figure B-7c - Precipitation - Diurnal Variation

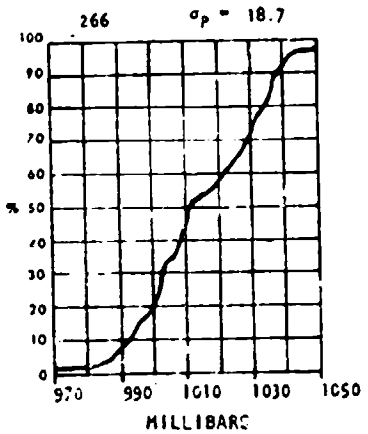


Figure B-8a - Sea Level Pressure - Cumulative Distribution

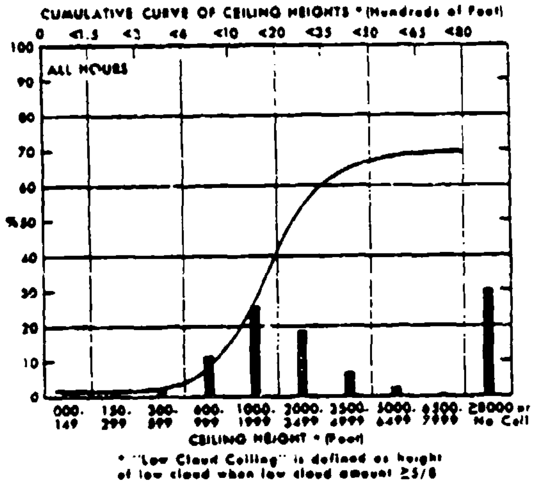


Figure B-9a - Ceiling Height

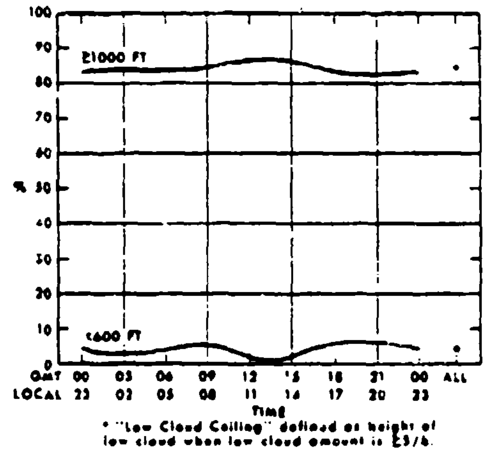


Figure B-9b - Ceiling Height - Diurnal Variation

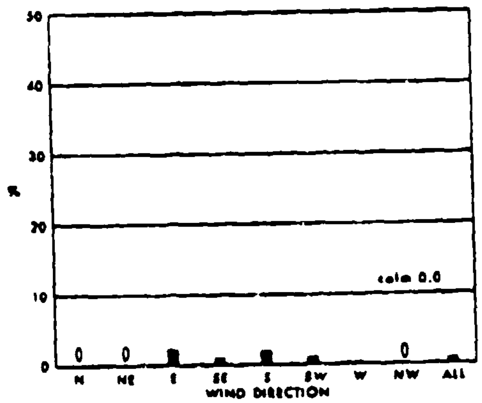


Figure B-10a - Fog versus
Wind Direction

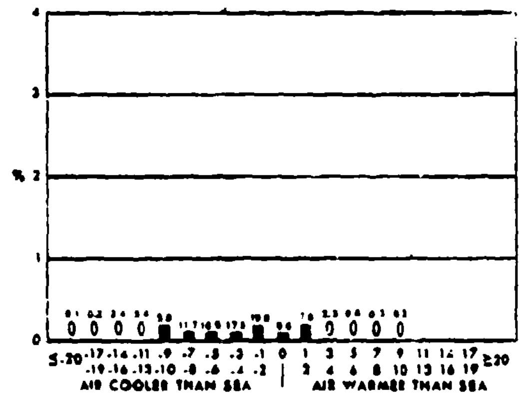


Figure B-10b - Fog versus
Air - Sea Temperature Difference

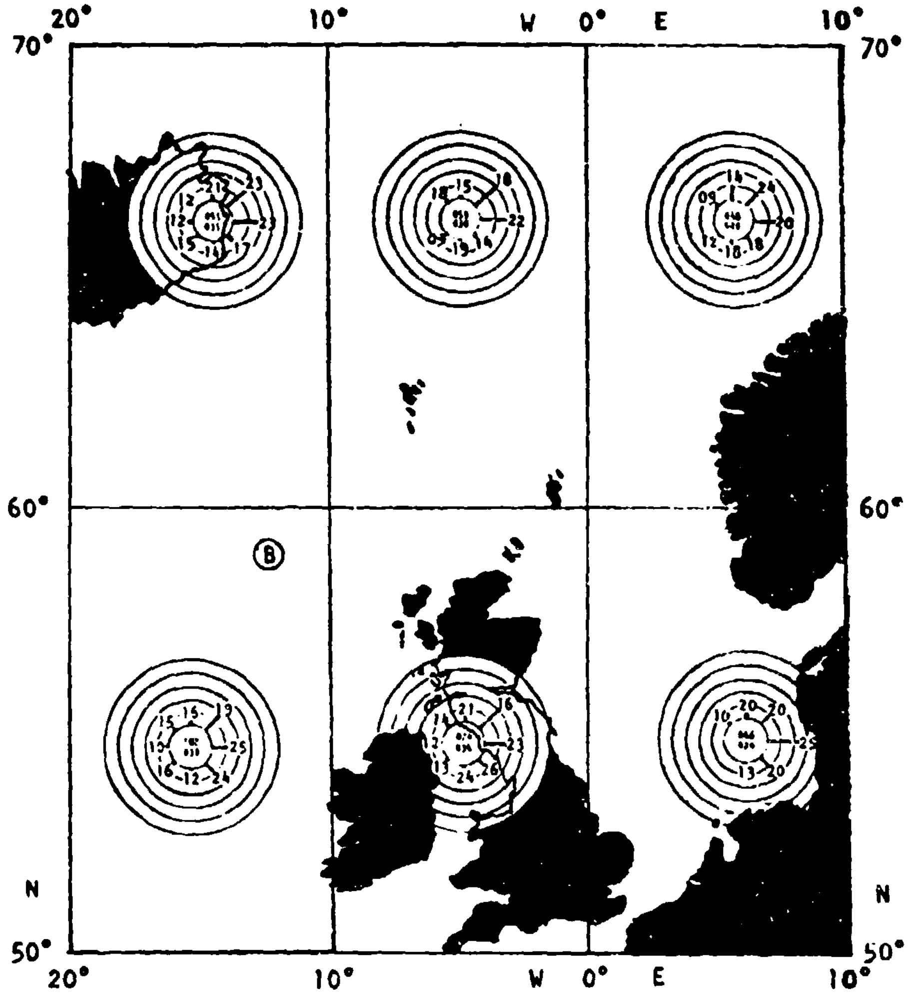


Figure B-11a - Low Pressure Centers

NO OCCURRENCES
REPORTED

Figure B-11b - Extratropical Cyclones

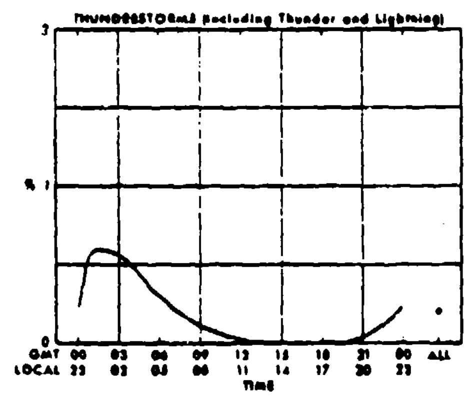
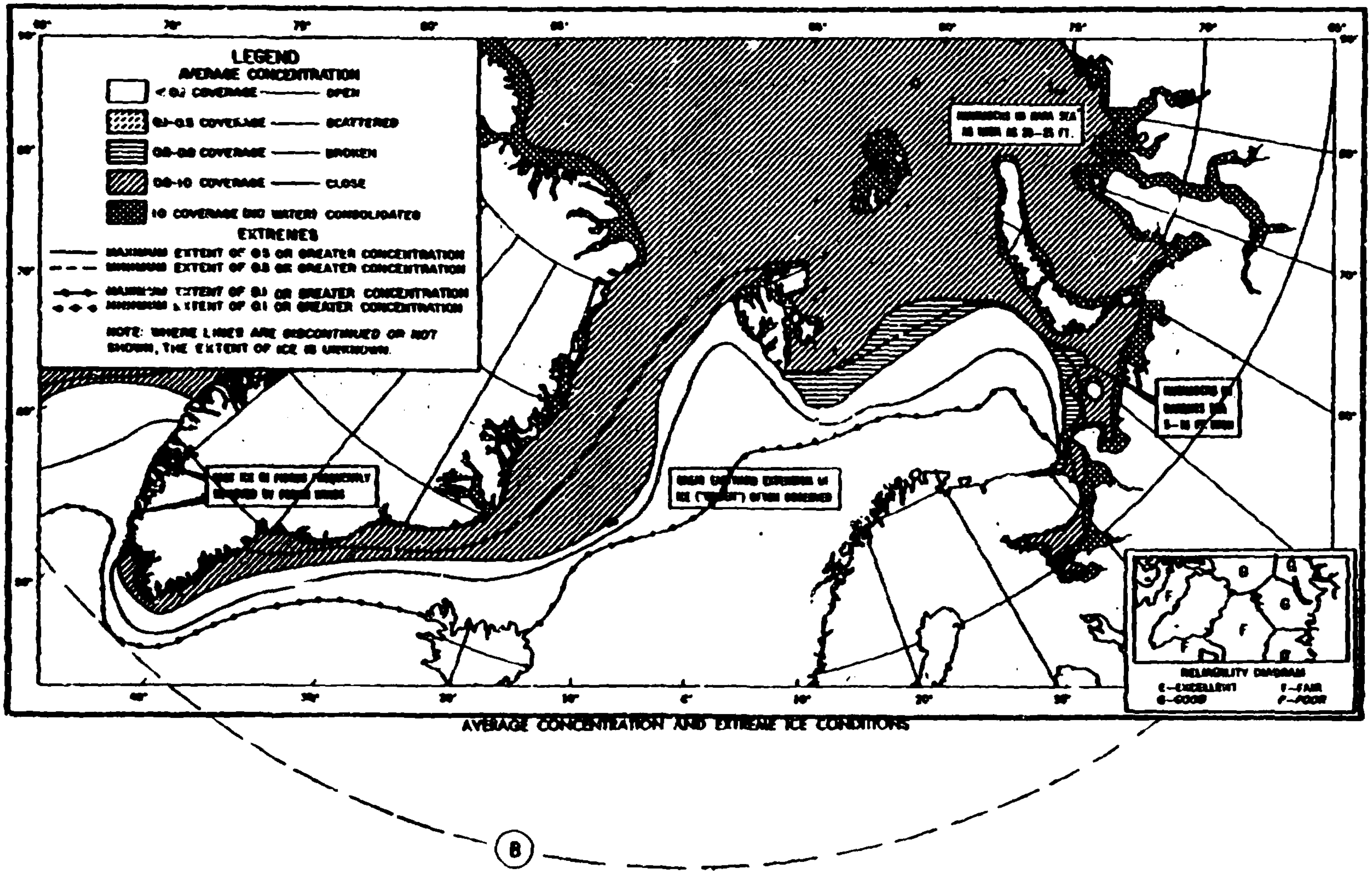


Figure B-11c - Thunderstorms



Fibure B-12a - Concentration

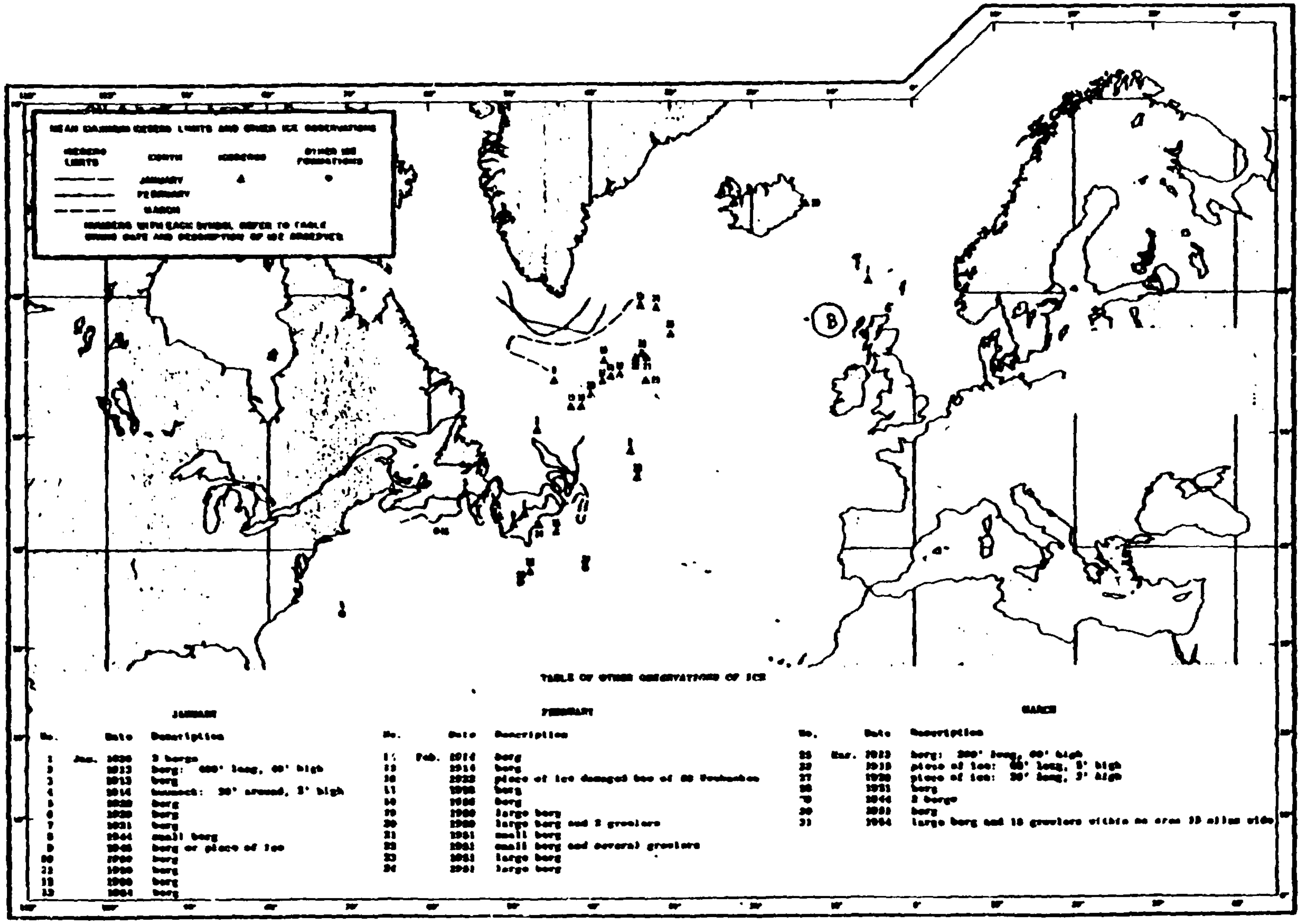


Figure B-12b - Icebergs

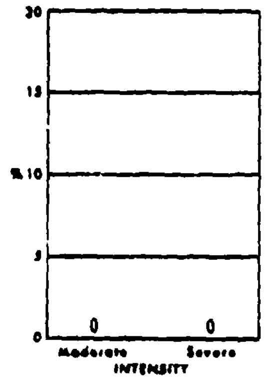


Figure B-13a - Percentage frequency of moderate and severe potential for superstructure icing

APPENDIX C

MARINE CLIMATOLOGY OF THE EASTERN MEDITERRANEAN:

33°30' - 35°0'N, 29°30' - 30°30'E (OFF CYPRUS)

PART I. GENERAL MARINE CLIMATOLOGY OF THE EASTERN MEDITERRANEAN: 33°30' - 35°0'N, 29°30' - 30°30'E (OFF CYPRUS)

1. A general climatology for the oceanographic area defined by 33°30' to 35°0'N - 29°30' to 30°30'E is developed. The area is denoted as Location C on Figure C-1 and is considered important to U.S. Navy operations because of its proximity to Cyprus as well as the Middle East. The prime data source is Reference 5 though some data have been derived from Reference 6.

As its name implies, the landlocked Mediterranean is an extension of the Atlantic Ocean. Due to a high evaporation rate, the inflow of water to the Mediterranean from rivers is insufficient to maintain the sea level, and hence waters from the Atlantic are required to flow in through the Strait of Gibraltar to compensate for this deficiency.

2. The primary current affecting the climatic pattern in the Mediterranean Sea flows in a counterclockwise direction and is from part of the water of the Portugal Current which enters the Strait of Gibraltar and flows along Africa's north coast, see Figure C-1. After passing Cape Bon, the current continues southeasterly towards Port Said. At the eastern end of the Mediterranean, it turns northward to return along the southern European coasts. In following the Mediterranean coasts. the current forms counterclockwise flows in other seas, e.g., the Aegean and the Adriatic. The outflow back to the Atlantic, is a subsurface one, westward through the Strait of Gibraltar, and beneath the incoming surface current. The returning current is subsurface because due to the high evaporation rate, it is extremeiy saline and dense, and therefore it sinks.

3. As compared to the Northeastern Atlantic Locations A and B, the overall weather at Location C is somewhat benign from the viewpoint of naval operations. The environment here is, in general, warmer, clearer, dryer (especially in the summer), and due to lower wind speeds and limited fetch (area and length over which the wind blows in the same direction and at the same speed), the waves are generally of lower heights. Thus, the dynamics of the naval platforms themselves may be of somewhat less concern to overall mission effectiveness in the Eastern Mediterranean than in the Northeastern Atlantic; however, the atmospheric conditions which affect

communication, detection, and tracking systems may be of more importance. As refractivity data becomes available and is analyzed, it may become apparent that electromagnetic phenomena are more important here in the Mediterranean than in the Northeastern Atlantic.

Figure C-2 illustrates that the daily mean atmospheric pressure is 1017 millibars in winter, 1014 millibars in spring, 1010 millibars in summer, and 1016 millibars in fall.

4. Upon considering the primary environmental parameters affecting ship performance, e.g., waves and wind, as well as overall weather occurrence (precipitation), January was selected as the most severe month and thus is taken to be the winter or worst season. Similarly, April is denoted as spring, July as summer, and October as fall. As before, the emphasis in this general climatology will be placed on the worst or winter season, though comparisons to the other seasons will be made.

5. Winds are caused by differences in atmospheric pressure, which are caused by variations of vertical air temperature, between two locations. The occurrence of any higher wind speeds at Location C indicates the existence of a noticeable pressure gradient and in winter 2.5 percent of all observed winds exceed or equal gale forces of 34 knots. Lower pressure systems occur less often in summer when gale force winds are observed less than 1 percent of the time. The most likely wave heights to accompany the winter gale force winds are between 13 and 16 feet and from the west.

6. Generally sea direction coincides with wind direction which in winter and fall is predominantly from the north-northwest-west and in spring and summer from the west. In winter, 3 percent of all observed wave heights exceed 12 feet, while in spring only 1.4 percent and in summer 1.3 percent exceed 12 feet, see Figure C-3. Rarely do waves exceed 12 feet in fall. Though no swell data are available, it is expected that swells of several feet may come from the west and northwest during the fall and winter. Swells from the east should be negligible. Observed wave periods are generally 7 seconds or less. however, periods of 13 seconds or more have been observed in all but fall. The highest observed wave heights in winter have occasionally exceeded 20 feet and are generally of periods of 11 seconds or less.

7. The frequency of precipitation increases from a minimum in summer to a maximum in winter. Liquid precipitation may occur in all but summer, when no precipitation is reported, and hail occurs occasionally in winter and spring. Frozen precipitation, such as snow, does not occur. Thunderstorms, including lightning, occur most frequently in fall, e.g., 3.4 percent of the time, but can occur at any time of year.

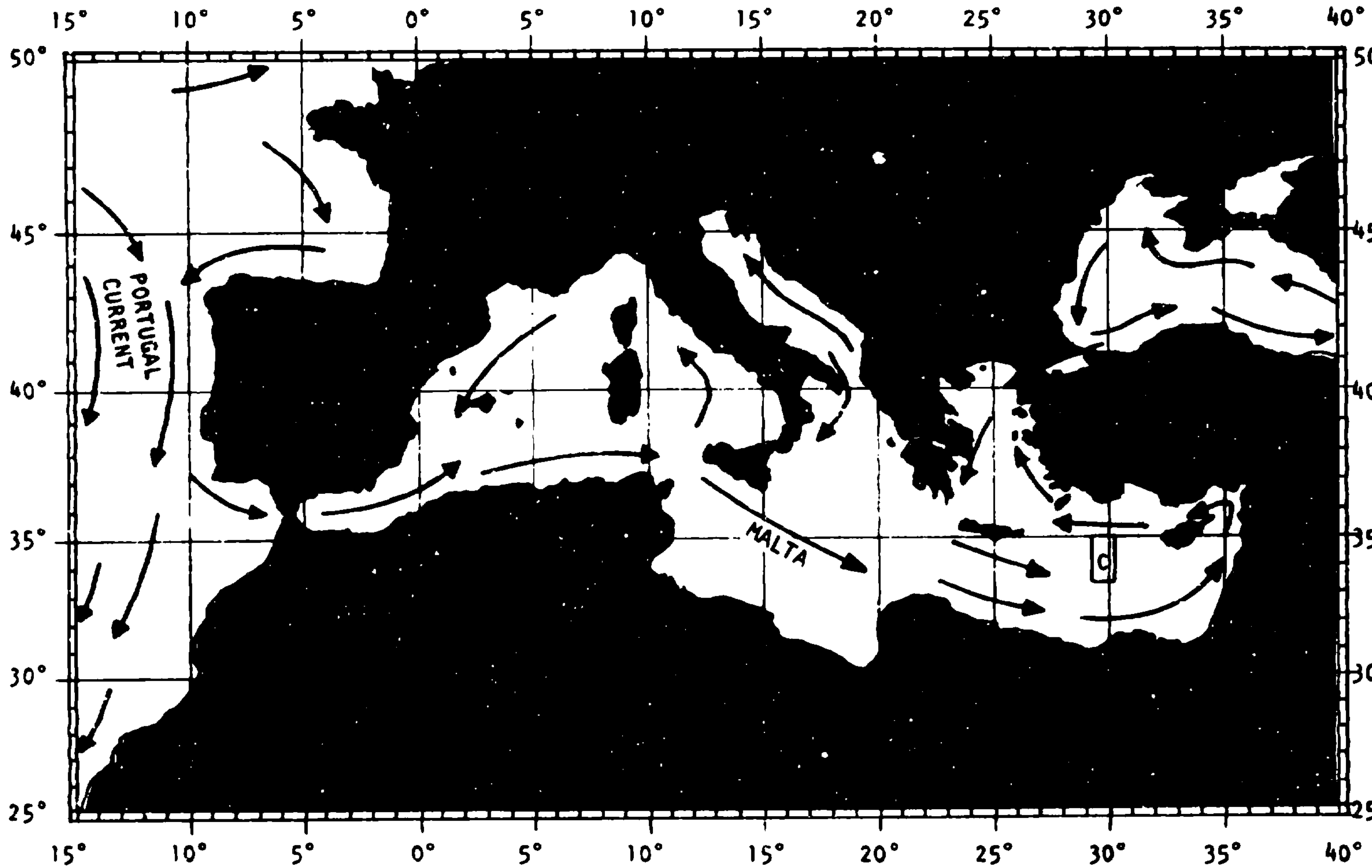
8. Fog occurs less than 15 percent of the time and is more common in summer than winter, usually occurring when the air temperature is from 2°F below to 4°F above the sea temperature. A more observed phenomenon is smoke or haze which occur in 0.3 percent of observations in winter, 2.5 percent in spring, 3.4 percent in summer, and 0.5 percent in fall.

9. The observed maximum, mean, and minimum temperatures are 76, 59.5, and 43.0°F in winter, 82.0, 63.3, and 50.0°F in spring, 93.0, 77.6, and 64.0°F in summer, and 91.0, 73.1, and 61.0°F in fall.

10. The sea surface temperature has a mean value of 62.3°F in winter, 62.6°F in spring, 76.2°F in summer and 74.1°F in fall. The relative humidity has a daily mean of 71 percent in winter, 76 percent in spring, 77 percent in summer, and 73 percent in fall.

11. During the winter, the average visibility frequency of occurrence is 0.6 percent for less than 2 nautical miles, 1.6 percent for less than 5 nautical miles, 10.5 percent for less than 10 nautical miles and 88.0 percent for greater than 10 nautical miles and does not vary substantially over the rest of the year. Low visibility, e.g., less than 50 yards, occurs jointly with a low ceiling height, e.g., less than 150 feet, in winter and fall in 0.1 percent of observations.

12. The maximum number of hours of daylight occurs in June when the sun is above the horizon about 14½ hours. The minimum number of hours of daylight, 10 hours, occurs in late December and early January.



AREA C = 33°30' N -- 35° N,
29°30' E — 30°30' E

FIGURE C- 1 - Generalized Currents for the Mediterranean Sea

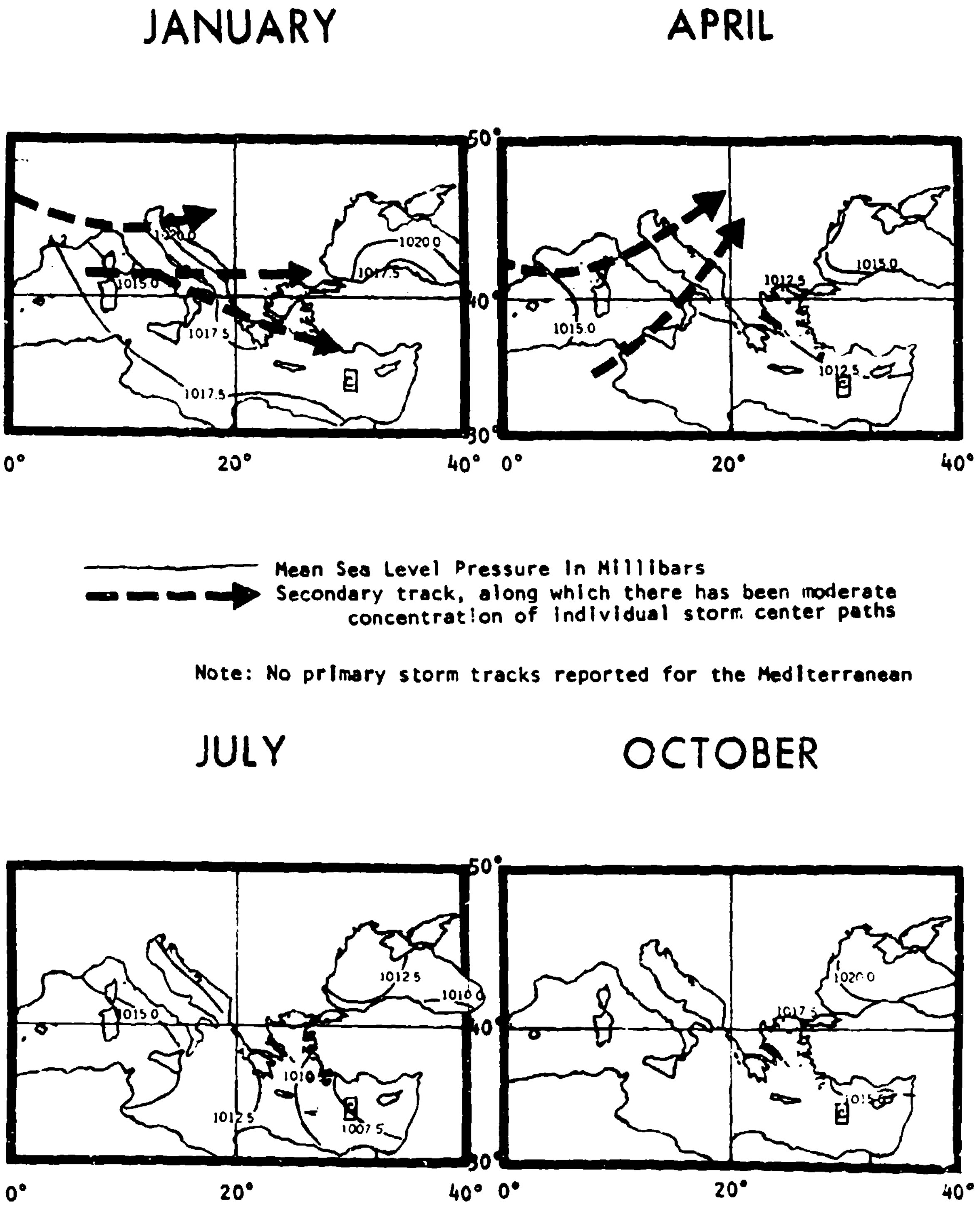


Figure C-2 - Seasonal Mean Sea Level Pressures and Storm Tracks

AREA C = 33°30' N – 35° N,
29°30' E – 30°30' E

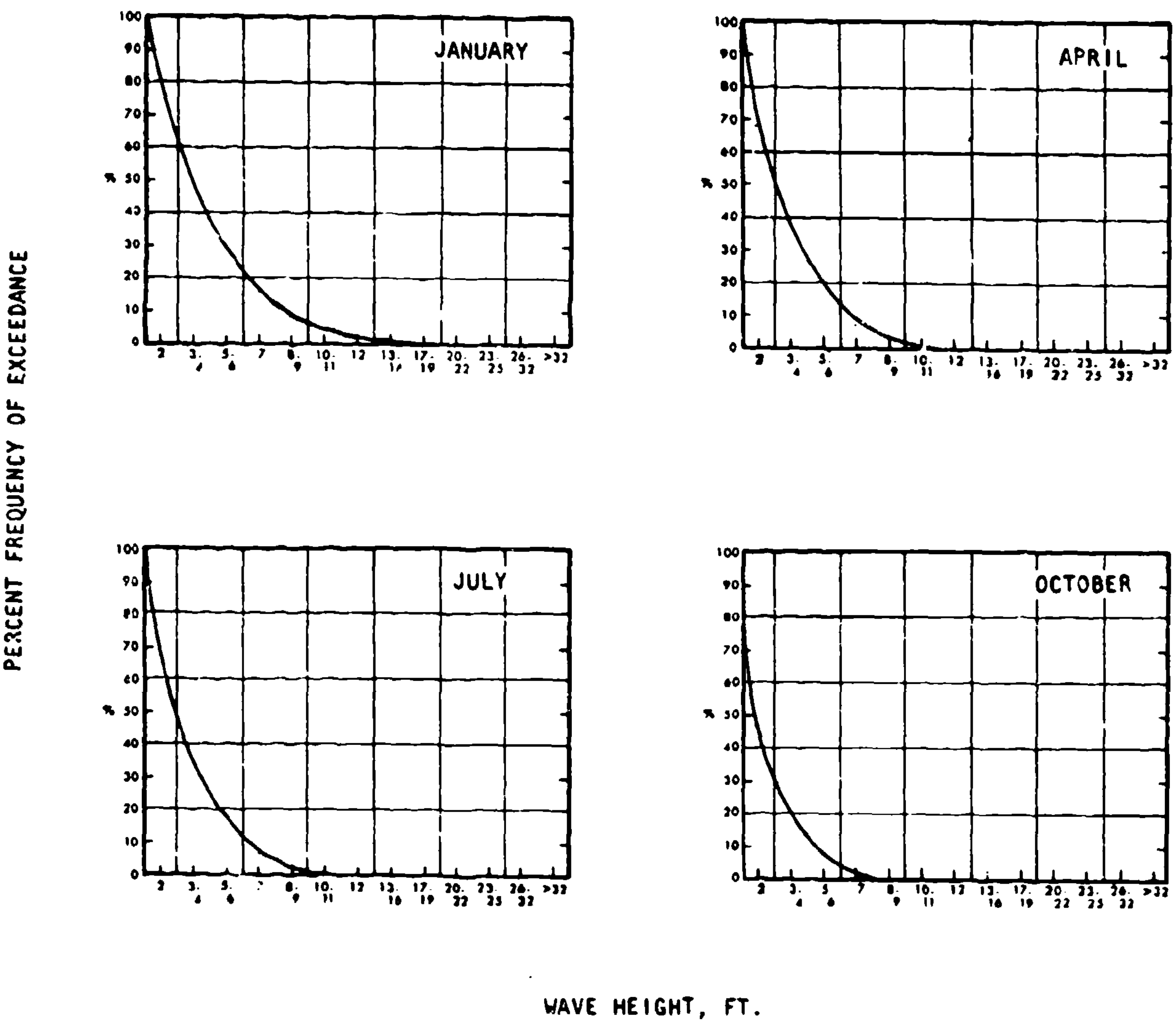


Figure C-3 - Seasonal Wave Height Exceedances for the Eastern Mediterranean

PART II. WINTER (JANUARY) CLIMATOLOGY OF THE EASTERN MEDITERRANEAN: 33°30' - 35°0'N, 29°30' - 30°30'E (OFF CYPRUS)

The following data graphs are derived primarily from Volume 8 of the Mediterranean Marine Areas (Area 29) of Reference 5, for the worst wind-wave season, January. Figure C-11a is adopted from Reference 3.

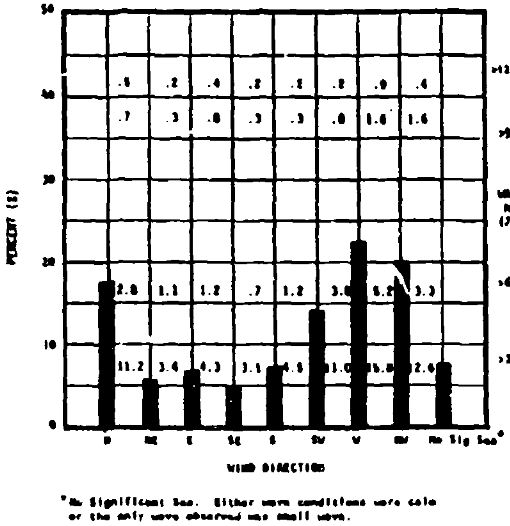


Figure C-1a - Sea Height by Wind Direction

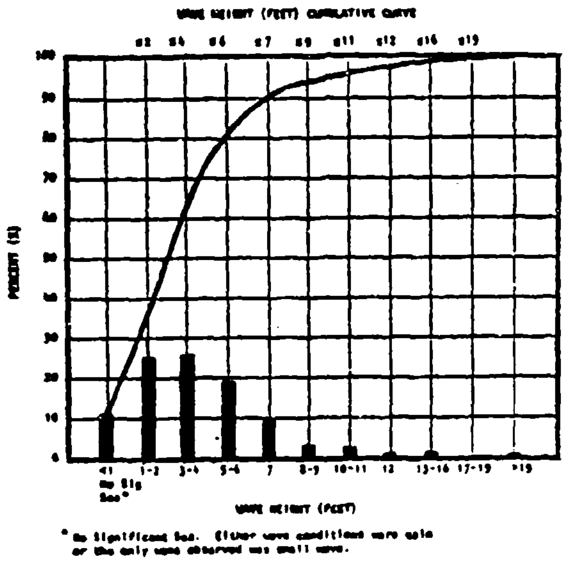


Figure C-1b - Sea Height - Cumulative Distribution

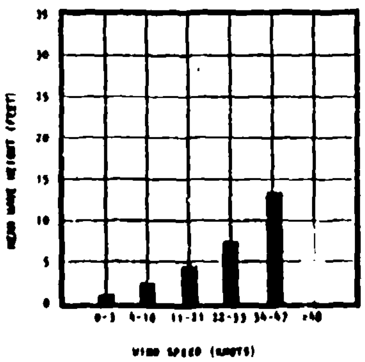


Figure C-1c - Mean Sea Height by Wind Speed

NOT AVAILABLE

Figure C-1d - Swell Height by Direction

NOT AVAILABLE

Figure C-1e - Swell Height - Cumulative Distribution

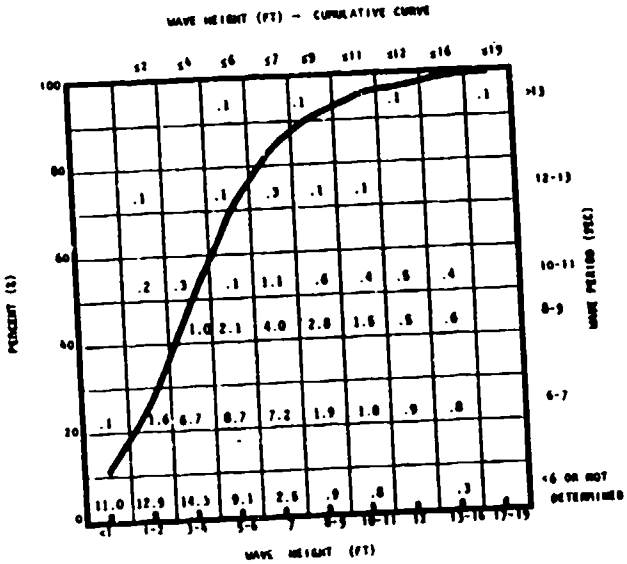


Figure C-1f - Wave Height and Period

NOT AVAILABLE

Figure C-1g - Return Periods for High Waves

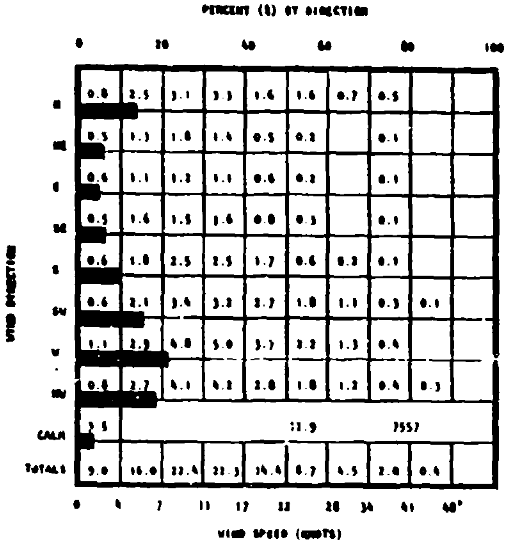


Figure C-2a - Wind Speed by Direction

NOT AVAILABLE

Figure C-2b - Return Periods for Maximum Sustained Winds

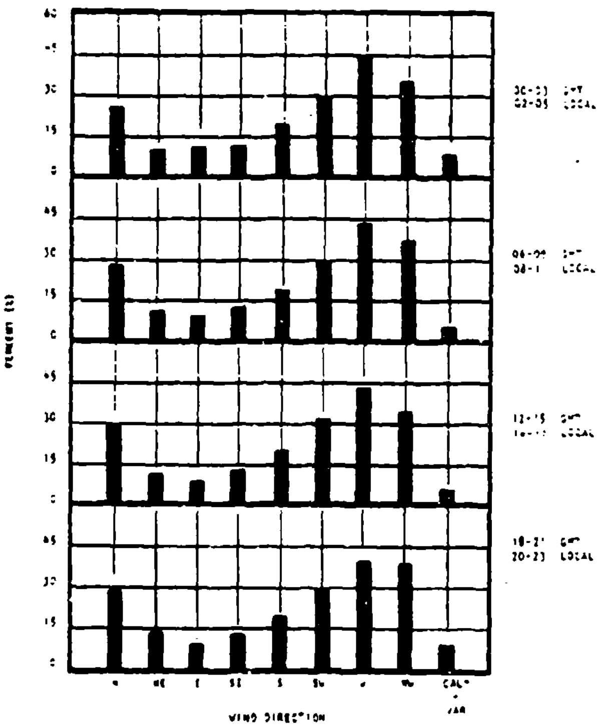


Figure C-2c - Wind Direction - Diurnal Variations

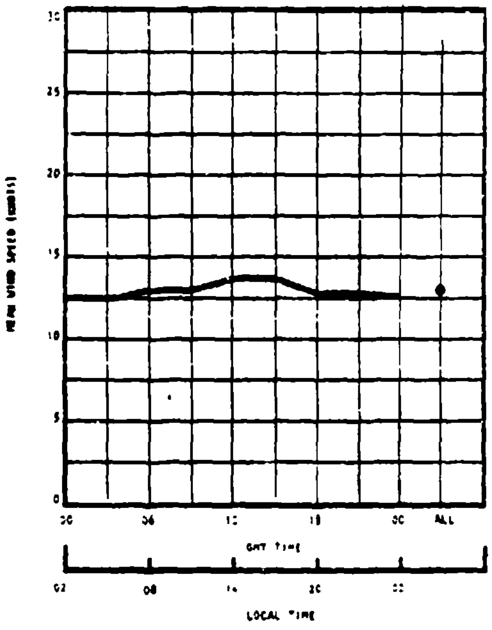


Figure C-2d - Wind Speed - Diurnal Variation

NOT AVAILABLE

Figure C-2e - Gale Persistence

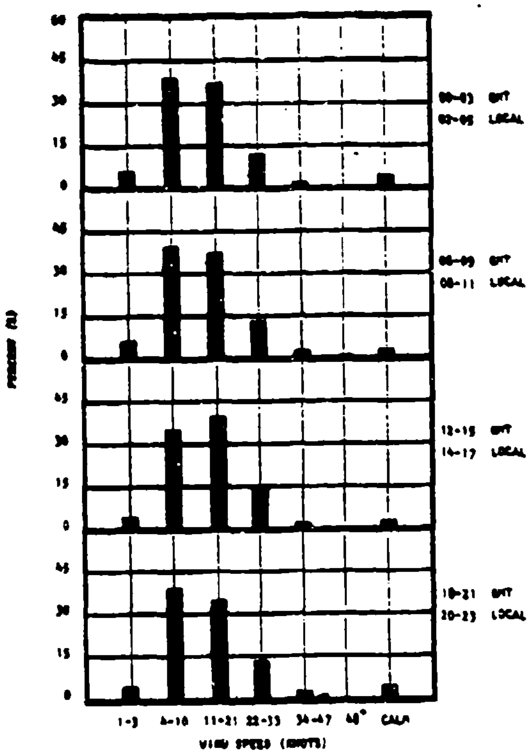


Figure C-2f - Wind Speed - Diurnal Variation

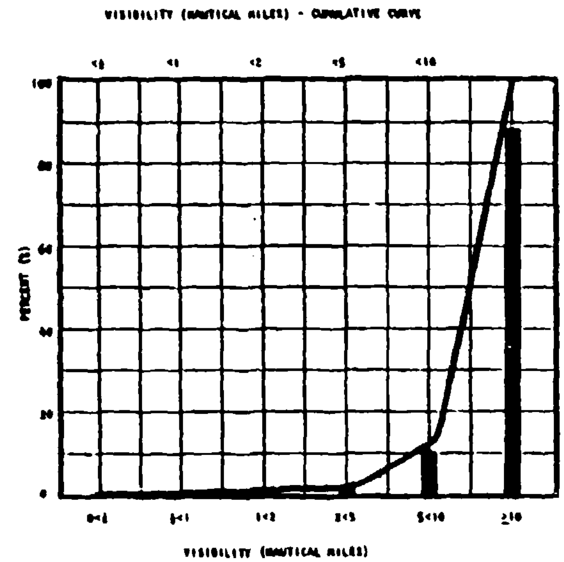


Figure C-3a - Visibility - Cumulative Distribution

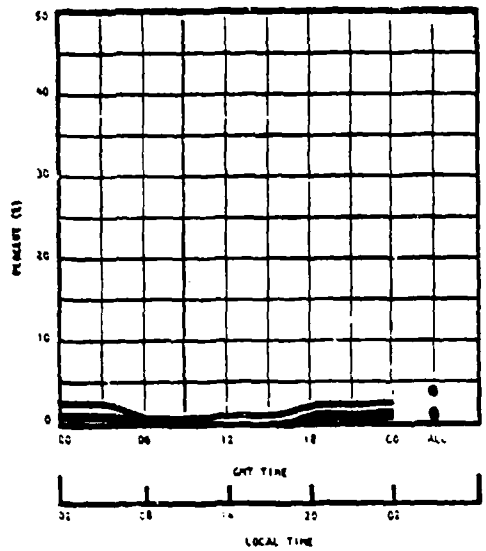


Figure C-3b - Visibility - Diurnal Variation

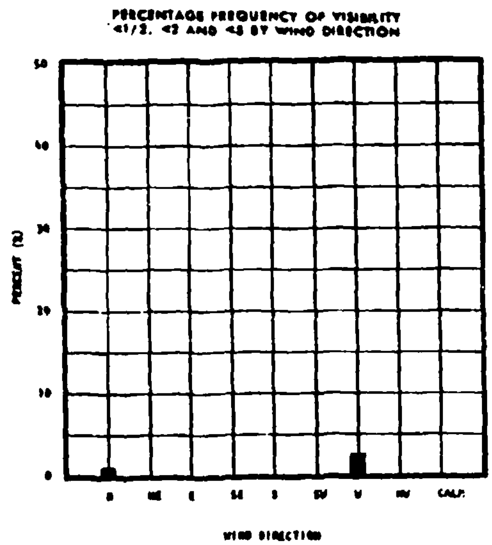


Figure C-3c - Visibility by Wind Direction

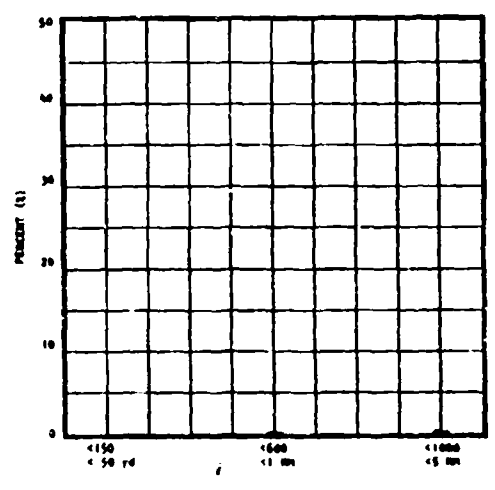


Figure C-3d - Low Visibility and/or Ceiling Height

NOT AVAILABLE

Figure C-3e - Visibility Persistence

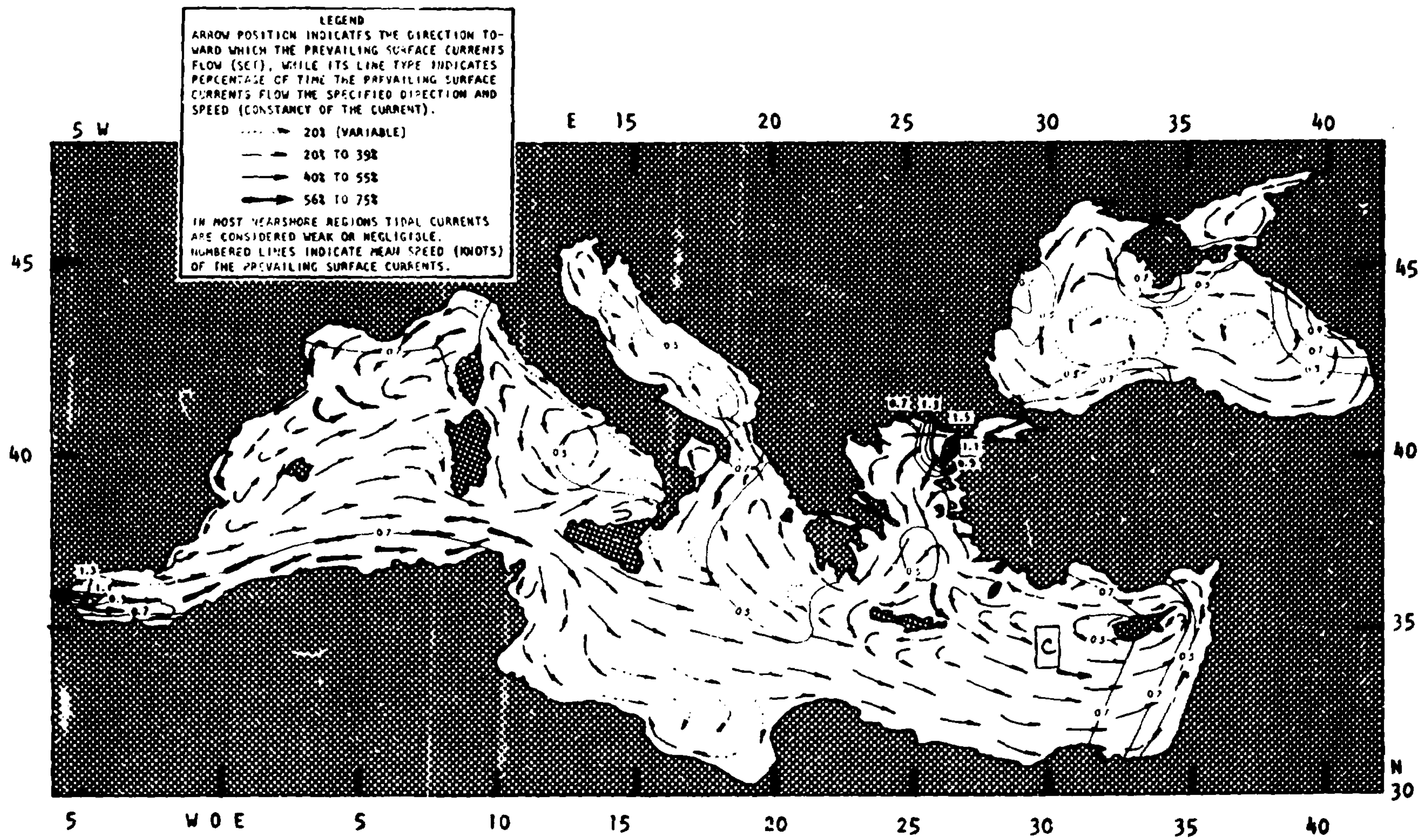
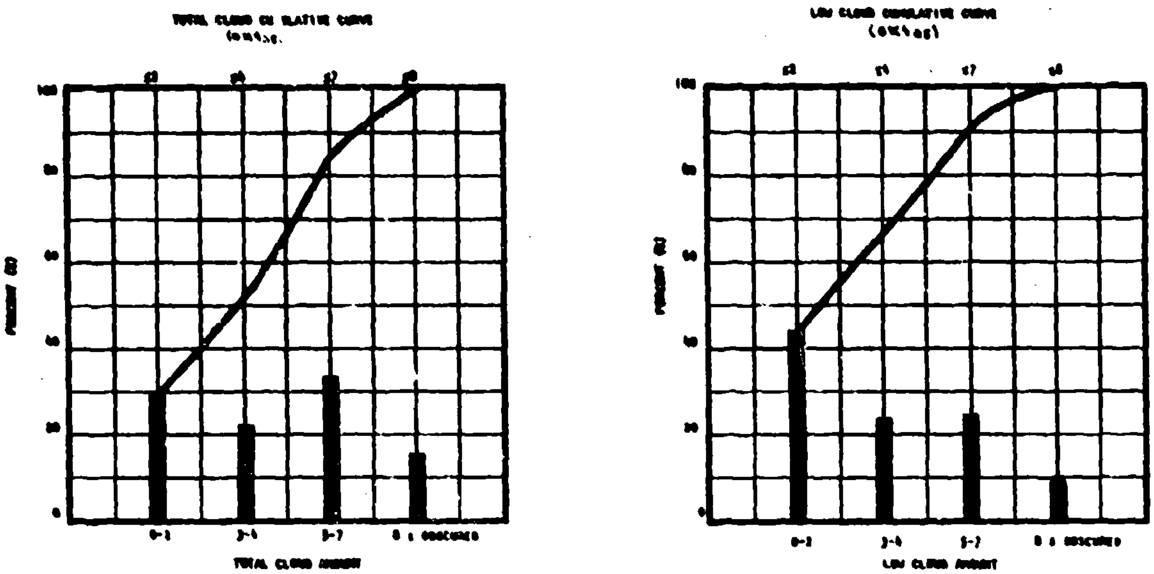


Figure C-4a - Mean Surface Current Speeds and Prevailing Directions



e C-5a - Cloud Amounts -
mulative Distribution

NOT AVAILABLE

Figure C-5b - Mean Cloud Amounts

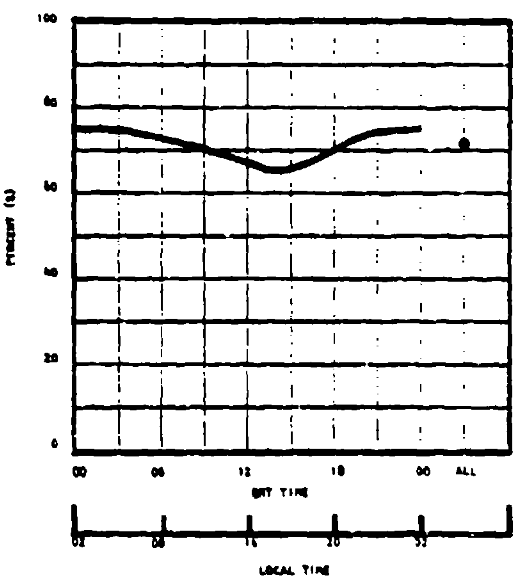


Figure C-5c - Good Cloud Conditions -
Diurnal Variation

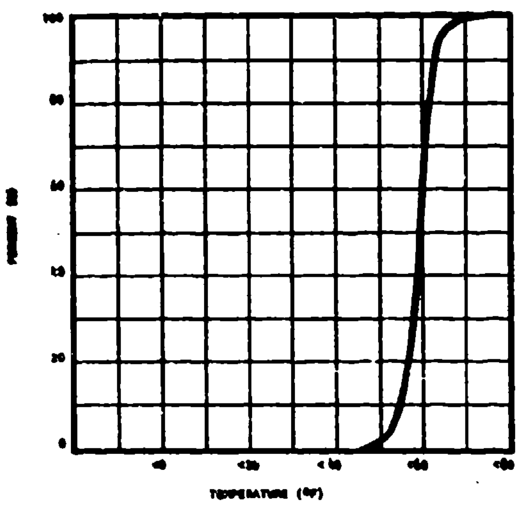


Figure C-6a - Air Temperature - Cumulative Distribution

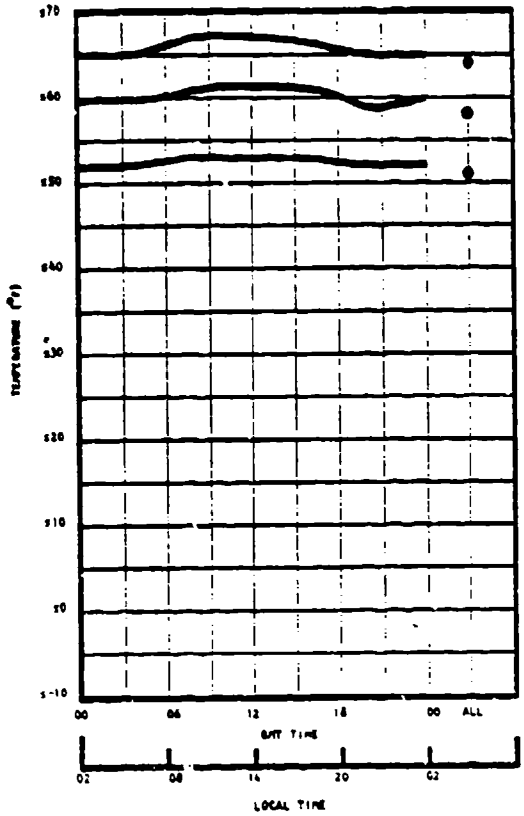


Figure C-6b - Air Temperature - Diurnal Variation

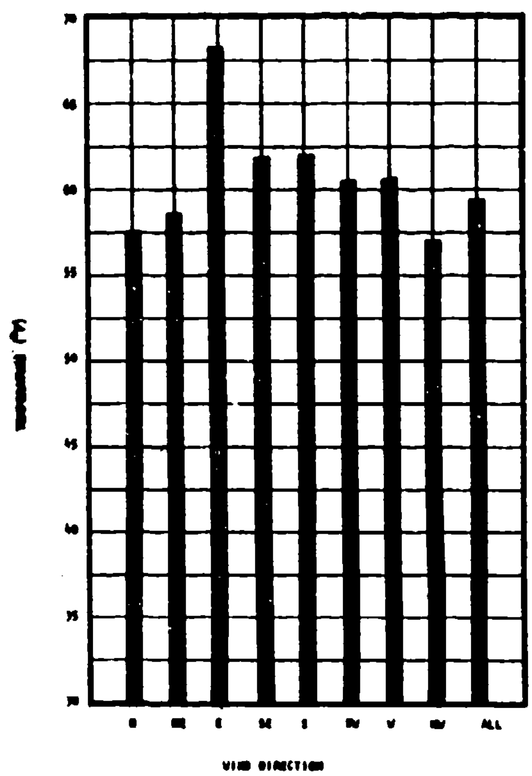


Figure C-6c - Mean Air Temperature by Wind Direction

NO OCCURRENCES

(SUB-FREEZING TEMP.)

REPORTED

Figure C-6d - Air Temperature and Gales

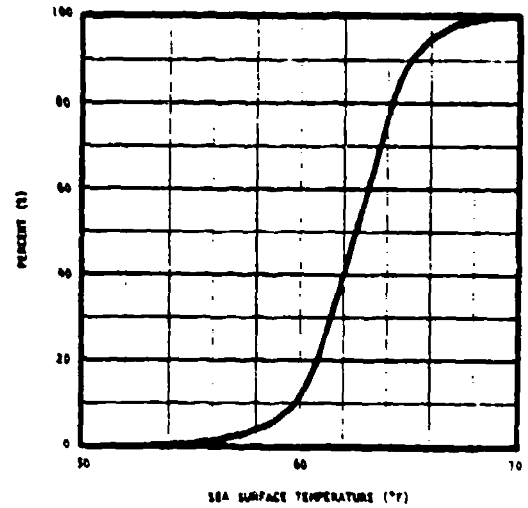


Figure C-6e - Sea Surface Temperature

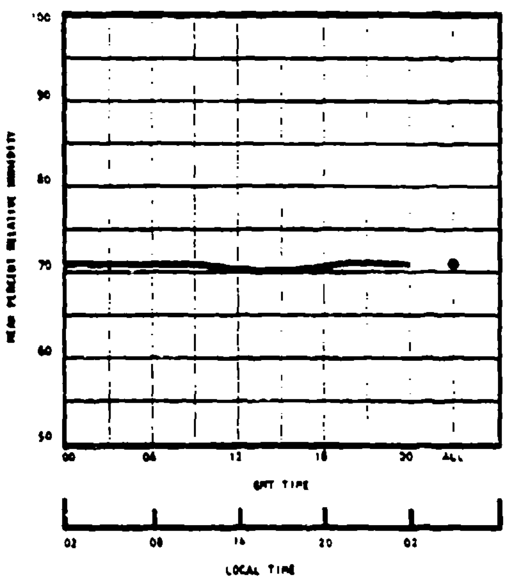


Figure C-6f - Relative Humidity - Diurnal Variation

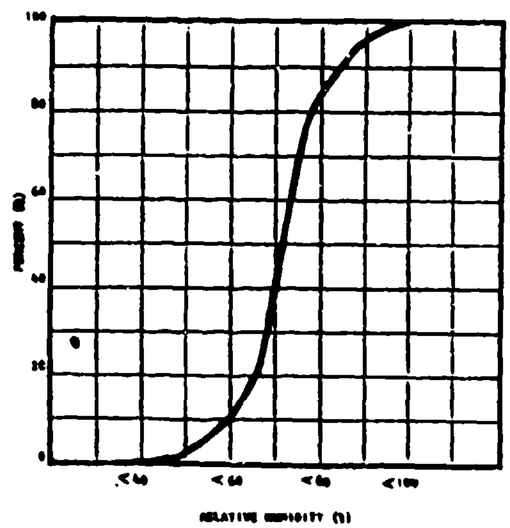


Figure C-6g - Relative Humidity - Cumulative Distribution

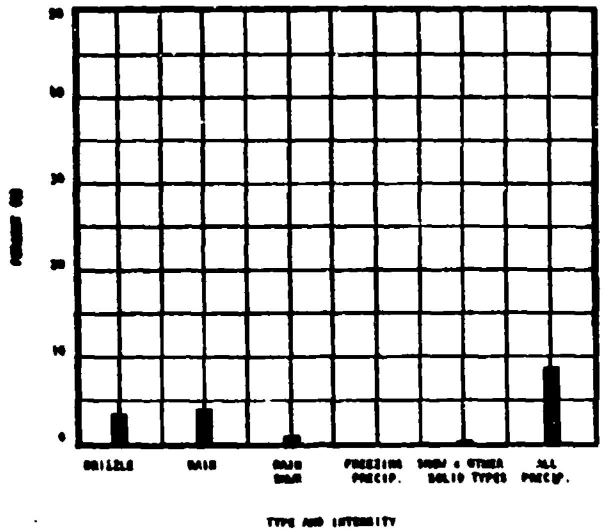


Figure C-7a - Precipitation by Type

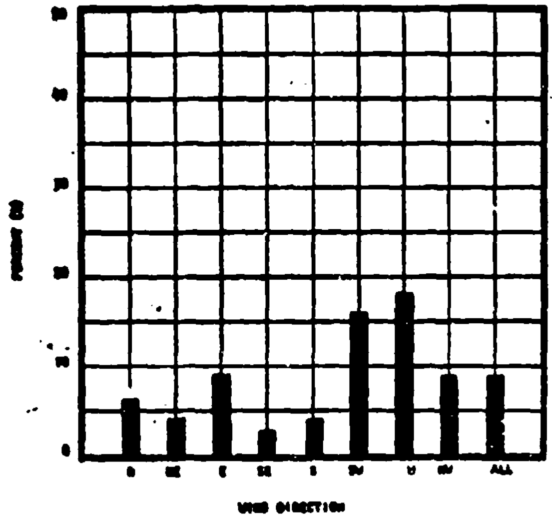


Figure C-7b - Precipitation by Wind Direction

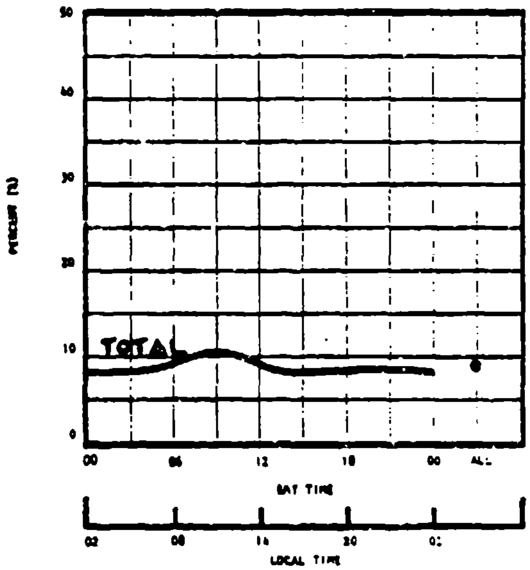


Figure C-7c - Precipitation - Diurnal Variation

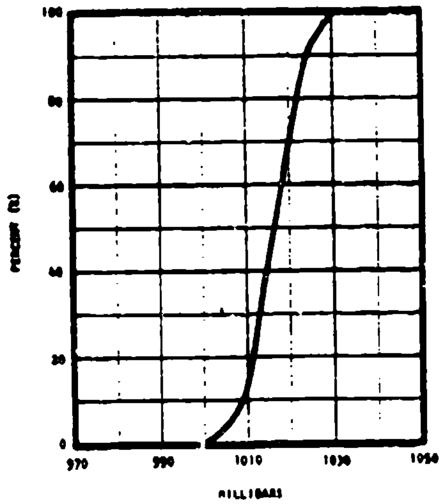


Figure C-8a - Sea Level Pressure - Cumulative Distribution

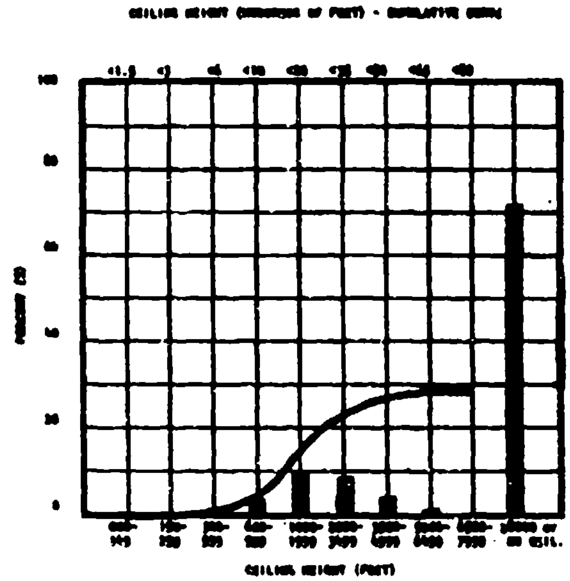


Figure C-9a - Ceiling Height

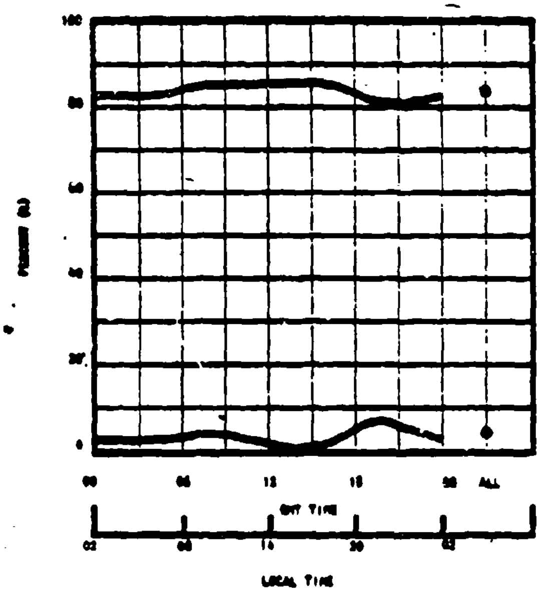


Figure C-9b - Ceiling Height - Diurnal Variation

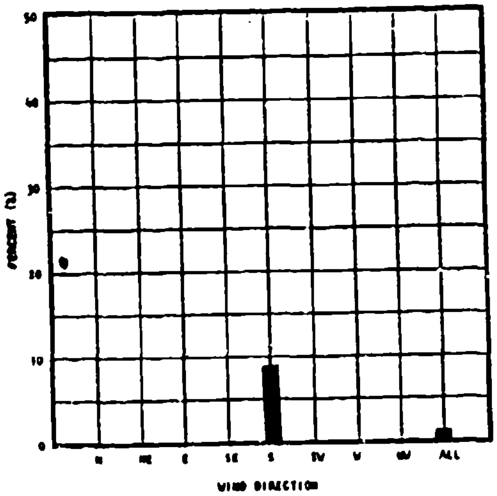


Figure C-10a - Fog versus
Wind Direction

NEGLIGIBLE OCCURRENCE
OF FOG REPORTED

Figure C-10b - Fog versus
Air - Sea Temperature Difference

(See Next Page)

NO OCCURRENCES REPORTED

Figure C-11a - Low Pressure Centers

Figure C-11b - Extratropical Cyclones

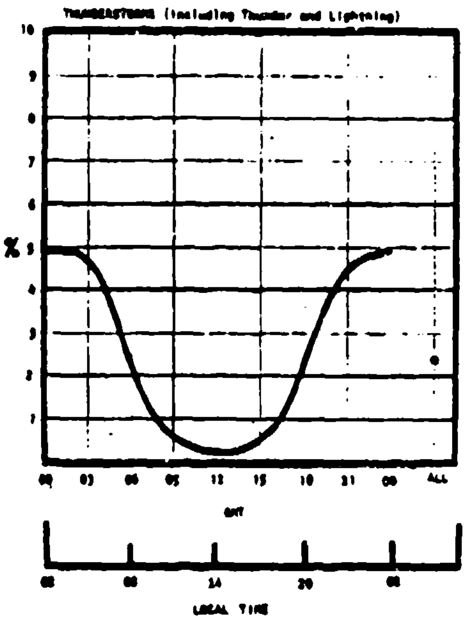


Figure C-11c - Thunderstorms

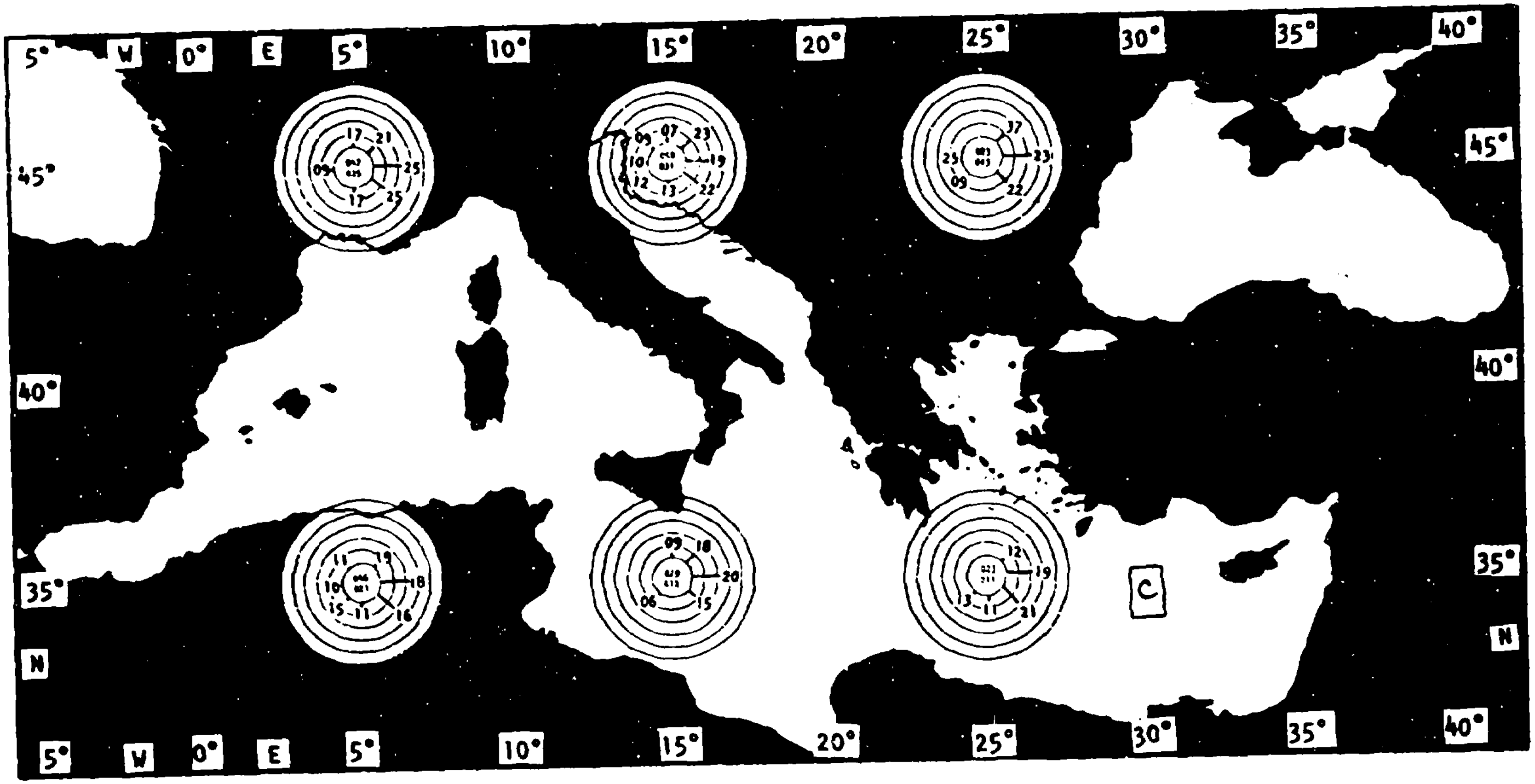


Figure C-11a - Low Pressure Centers

NO OCCURRENCES REPORTED

Figure C-12a - Concentration

Figure C-12b - Icebergs

Figure C-13a - Percentage frequency
of moderate and severe potential
for superstructure icing

APPENDIX D

MARINE CLIMATOLOGY OF THE JAPAN SEA:

39°N, 129°E (OFF KOREA)

PART I. GENERAL MARINE CLIMATOLOGY OF THE JAPAN SEA: 39°N, 129°E (OFF KOREA)

1. A general climatology for one location in the Japan Sea is developed. The location at approximately 39°N, 129°E is denoted as Location D and is approximately 74 nautical miles east of the natural harbor at Wonsan Hang, see Figure D-1. The location is considered important to U.S. Navy operations from the viewpoint of a long-term variable intensity naval encounter.

The prime data sources for this general climatology are References 5, 7, 8, 9, and 10. Though not used in this work, Reference 11 provides a rather comprehensive description of the coastlines of Korea and could be useful in developing parameters important to amphibious operations.

2. The climate of the greater part of eastern Asia is dominated by the monsoons, with northerly winds in winter and southerly winds in summer. This seasonal alternation of winds has a primary effect on the other elements of weather. The winds are similar in many ways to those of India, though in India it is the southwest or summer monsoon which is referred to as "the monsoon" season while in eastern Asia "the monsoon" season generally refers to the winter season.

3. The local surface current regimes in the Japan Sea are slightly varied by season, see Figure D-1. The warm Tsushima Current flows north-northeastward west of Kyushu, and the main branch flows through the Korea Strait where both its speed and direction may be influenced by tidal currents with occasional speeds up to 3 knots. After flowing through the Korea Strait, the Tsushima Current divides and a small branch flows northward along the east coast of Korea while the main branch flows northeastward along the Japan coast.

The counterpart in the Pacific of the cold Labrador Current in the North Atlantic is the Kamchatka Current, which originates in the Bering Sea and flows southwestward down the east coast of Kamchatka, and on down as far as about 36°N along the east coast of Japan. This current has no direct effect on the climatology of Location D and is thus not shown in Figure D-1, adapted from Reference 8. A second cold southerly current is the Liman Current which flows southward from the Gulf of Tartary along the Russian and Korean eastern coasts. In the warm season (summer), the

Liman Current is sometimes traced as far as the south coast of Korea but in the cold season (winter), does not reach the Korea Strait. Figure D-1 provides a seasonal view of the local current variations in the Japan Sea.

4. The winter monsoon winds, together with the weather that accompanies them, form the most interesting features of the climate. These winds are related to the high pressure area which forms over the cold pole of central Asia and, in general, most weather of that season is related to wind changes associated with the variations in this high-pressure area. Figure D-2, adapted from Reference 7, shows seasonal variations of the normal pressure distributions for the Japan Sea. At Location D the pressures vary from a high of 1025 millibars in winter to a low 1007 millibars in summer. Typhoons* have not been observed at Location D, however, increased typhoon activity in surrounding areas is observed in summer and fall. Thunderstorms have not been observed in winter though occur in summer about 0.5 percent of the time.

5. When fully developed, the winter monsoon wind blows as a moderate or fresh wind from the west to northwest at Location D. Temperatures accompanying it are usually between 30 and 40°F, and gale forces of 34 knots or greater are observed about 4.0 percent of the time. Seventy five percent of observations show wind forces of less than 22 knots. The winter monsoon is most persistent from about 10° to 18°N while north of 35°N the direction is often reversed and southwesterly winds are not uncommon in winter, occurring about 9 percent of the time. During the summer monsoon, southerly winds predominate and are in general weaker and less persistent than the northerly winds of winter. At Location D, the direction is usually between southeast and south, though there are also frequent winds from the north and northwest. During the passage of typhoons the winds may occasionally reach gale force. In summer 97 percent of observations show winds of 22 knots or less, and the southerly winds are generally accompanied by temperatures between 60° and 70°F.

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*The hurricane (maximum sustained winds are $\geq$ 64 knots) stage of a tropical cyclone is known as a typhoon in the western Pacific. A tropical cyclone is a cyclone of tropical oceanic origin, has no weather fronts per se, and derives most of its energy from a complex system which depends to a great extent upon warm sea surface temperatures (> 80°F), see Reference 12.

6. The seasonal variation of wave height at Location D is given in Figure D-3. In winter, waves of 13 to 16 feet with periods of 9 seconds or less have occasionally been observed (3.9 percent of the time), though generally observed wave heights are between 3 and 4 feet. Fifty percent of all observed waves in winter are 4 feet or less. Very rarely have waves of 17 to 19 feet of height been observed. In summer, waves of 13 to 16 feet have been observed 1.3 percent of the time, though generally the observed waves are between 1 and 2 feet. Fifty percent of all observed summer wave heights are less than or equal to 2 feet. Rarely are waves of 17 to 19 feet height observed and are probably associated with nearby typhoon activity. In winter, it is expected that the wave direction will generally follow the wind direction, and due to a lack of storm activity in surrounding areas, swells are not usually expected. In summer, swells may be expected from typhoon activity in surrounding areas. Wave periods greater than 11 seconds have rarely been observed at Location D regardless of season.

7. The average annual rainfall at Location D is about 30 inches and rain is more common in winter than summer when the air near the surface is more stable and turbulence is restricted. In winter, precipitation is observed over 21 percent of the time and in summer only about 16 percent of the time. Snow occurs in winter 7.6 percent of the time and in spring 3.1 percent of the time. Hail has occasionally been observed in winter and spring.

8. One of the most unpleasant and dangerous (from the viewpoint of navigation) features of the summer is heavy fog occurrences. In summer, fog without precipitation occurs in about 14.5 percent of all observations and tapers off to 2.6 percent in fall and less than 1 percent in winter. In spring the occurrence begins to rise and is observed at 4.1 percent. Smoke or haze is also observed in summer (3.0 percent) and occasionally in winter (0.9 percent).

9. The observed maximum, mean, and minimum temperatures are 64, 39.6, and 17°F in winter, 64, 43.9, and 23°F in spring, 82, 65.1, and 50°F in summer, and 86, 79, and 57°F in fall.

10. The sea surface temperature has a mean value of 46°F in winter, 40°F in spring, 61°F in summer, and 69°F in fall. The relative humidity has a

daily mean of 73 percent in winter, 69 percent in spring, 86 percent in summer, and 78 percent in fall.

11. During the winter, the average visibility frequency of occurrence is 1.4 percent for less than 2 nautical miles, 3.6 percent for less than 5 nautical miles, 40.4 percent for less than 10 nautical miles, and 59.6 percent for greater than 10 nautical miles. Visibility is worsened in spring and summer and somewhat improved in fall. Low visibility, e.g., less than 50 yards, occurs jointly with a low ceiling height, e.g., less than 150 feet, up to 5.8 percent of the time in winter and as low as 1 percent of the time in summer.

12. The maximum number of hours of daylight occurs in June when the sun is above the horizon nearly 15 hours. The minimum number of hours of daylight, about 9.5 hours, occurs in late December and early January.

13. Bioluminescence (phosphorescence) is common in Korean waters, and is noted most often in late summer and fall; however, no data regarding bioluminescence for Location D has been located. The transparency of the waters of Location D is similar to that of the open ocean. While no large kelps are expected, porpoises and whales inhabit the open waters off Korea and possibly near Location D. Large schools of fish, as well as some sonic fish, abound in Korean waters and these as well as the larger forms may be confusing to the underwater listener as they are capable of returning echo ranging signals. The maximum level of sound pressure of fish noises is in the frequency range of 0.1 to 3.0 kilocycles.*

14. The color of the waters near Location D is generally green. The average sea surface salinity is about 34.0 percent in winter and spring and decreases to about 33.0 percent in summer and fall at Location D. Sea ice and superstructure icing are not expected in the winter season.

15. The expected times of survival** of a man immersed in the sea are less than 3 hours in winter, 1.5 hours in spring, and 12 hours in summer and fall.

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*It should be pointed out that this note of the abundance of marine life is taken from Reference 9, and thus may not reflect a totally accurate view of today's marine population.

**Survival time indicates the length of time a man in ordinary clothes and a life preserver can withstand immersion without fatal effects.

16. The depth of the waters at Location D is about 1000 fathoms (6000 feet) and the bottom is floored in mud.

D 39° N , 129° E

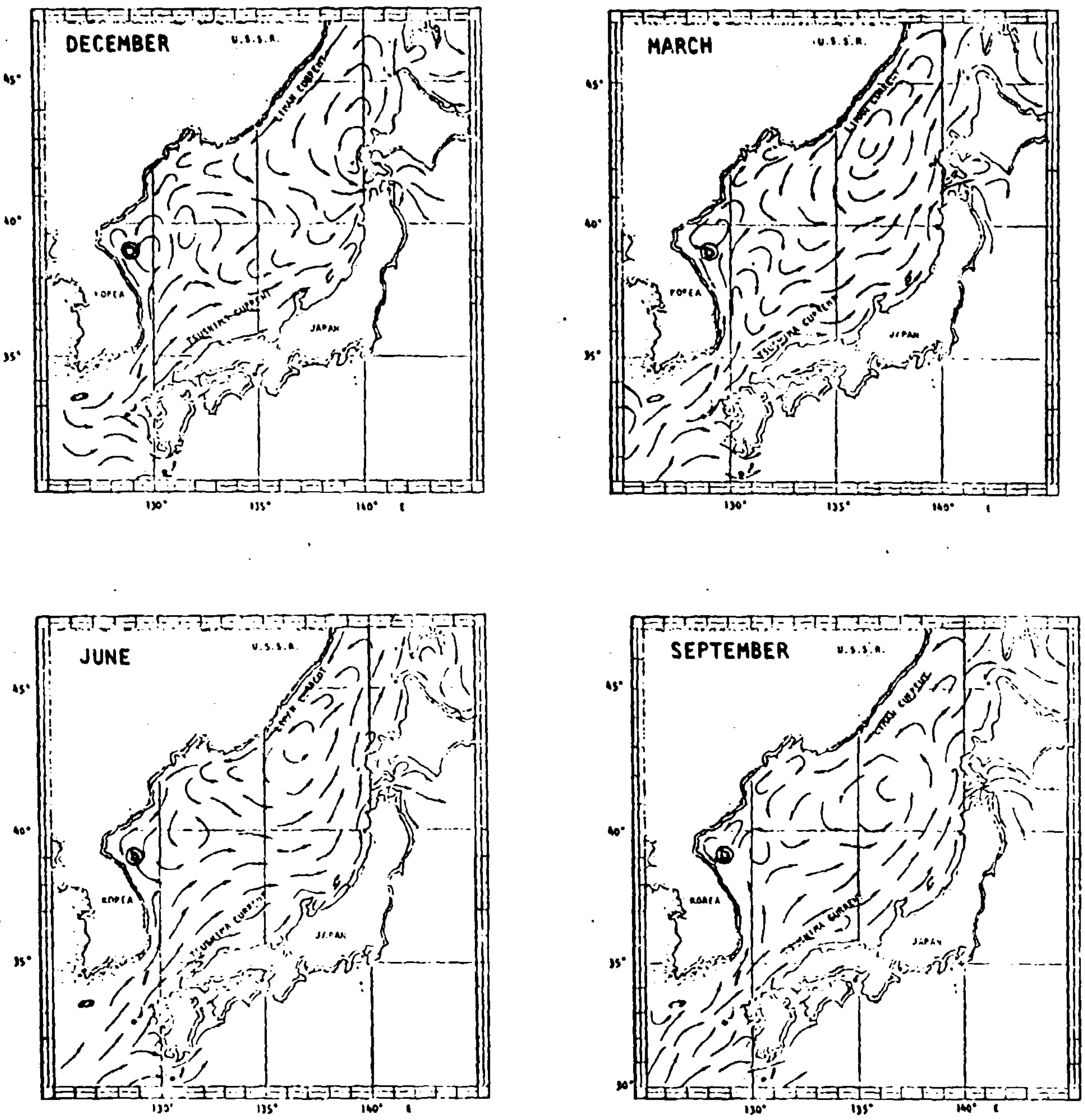


Figure D-1 - Seasonal Current Variations for the Japan Sea

Ⓓ 39°N , 129°E

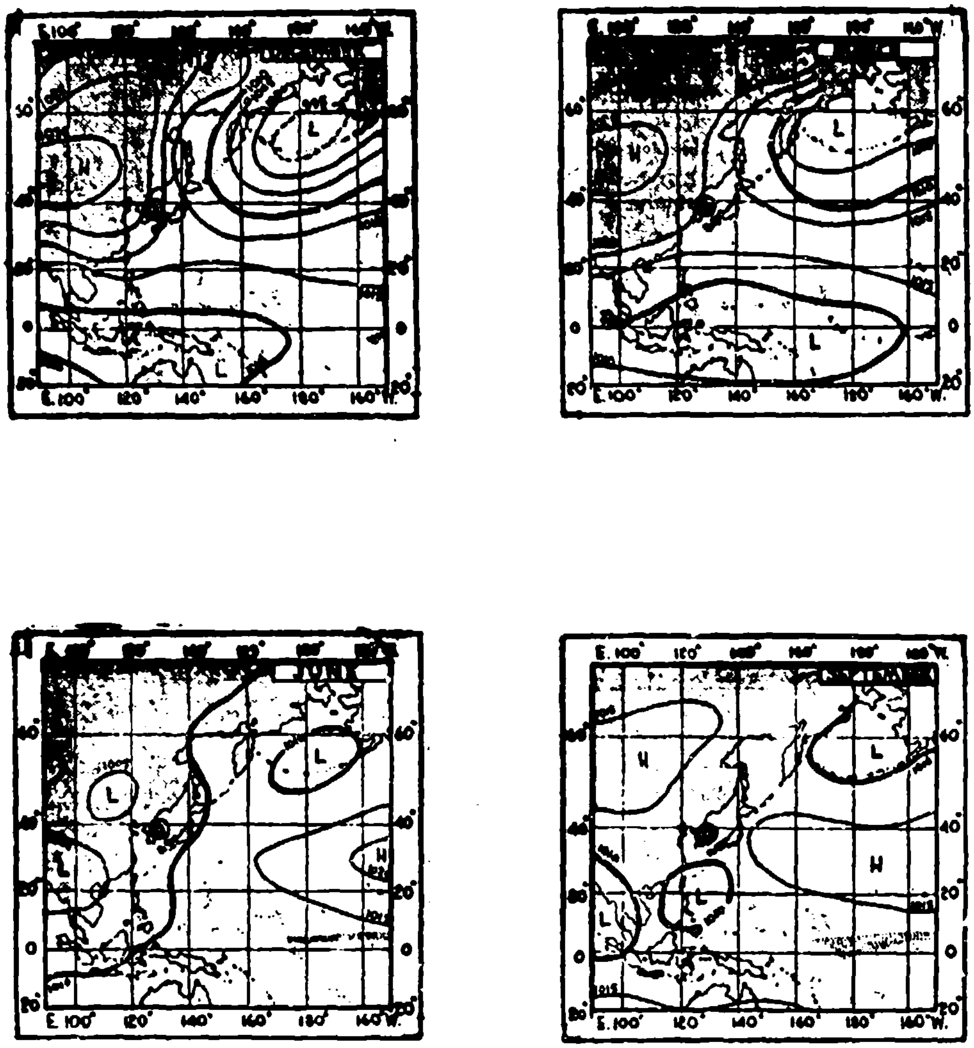


Figure D-2 - Seasonal Pressure Variations for the Japan Sea

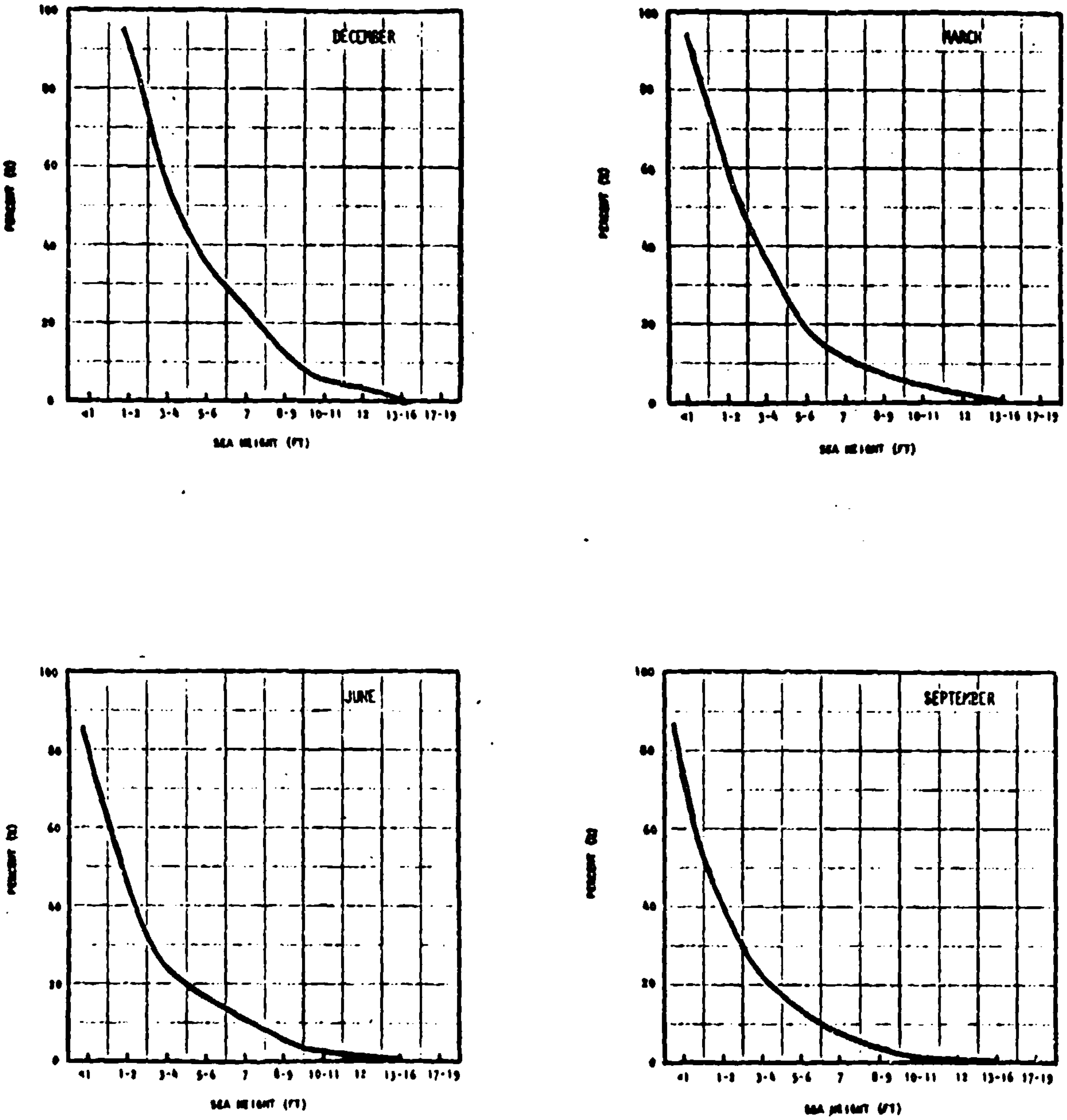


Figure D-3 - Seasonal Wave Height Exceedances for the Japan Sea

PART II. WINTER (DECEMBER) CLIMATOLOGY OF THE JAPAN SEA: 39°N, 129°E (OFF KOREA)

The following data graphs are derived primarily from Volume 9 of the Japanese and Korean Coastal Marine Areas (Area 25) of Reference 5 for the worst wind/wave season, December. Figure D-6d is developed from Reference 20. Figure D-6e is adopted from Reference 10. Figure D-11a is adopted from Reference 20.

NOT AVAILABLE

Figure D-1a - Sea Height by Wind Direction

NOT AVAILABLE

Figure D-1b - Sea Height - Cumulative Distribution

NOT AVAILABLE

Figure D-1c - Mean Sea Height by Wind Speed

NOT AVAILABLE

Figure D-1d - Swell Height by Direction

NOT AVAILABLE

Figure D-1e - Swell Height - Cumulative Distribution

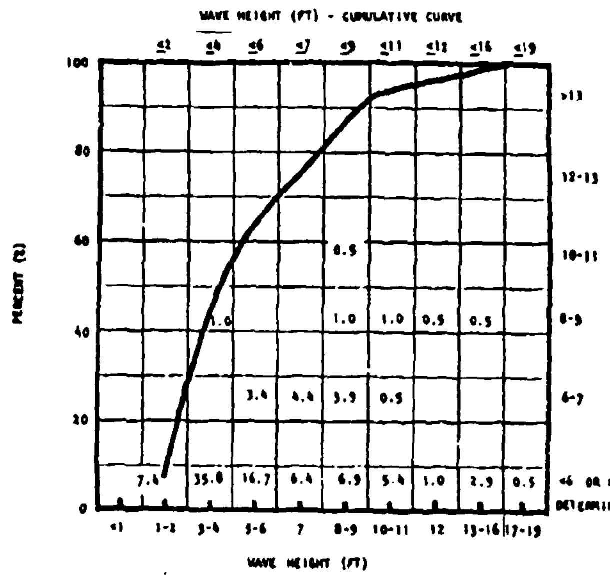


Figure D-1f - Wave Height and Period

NOT AVAILABLE

Figure D-1g - Return Periods for High Waves

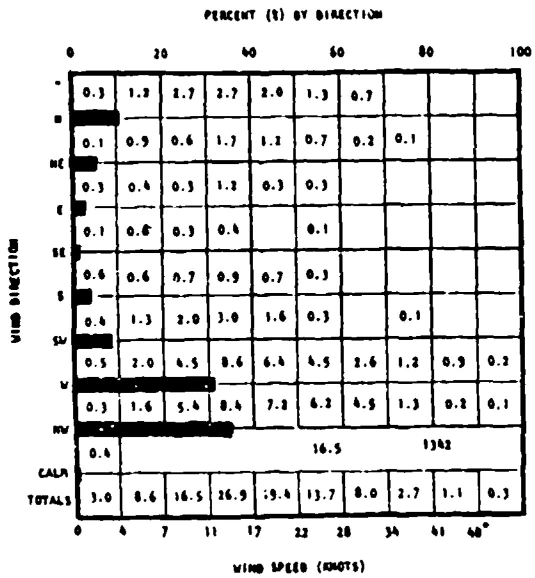


Figure D-2a - Wind Speed by Direction

NOT AVAILABLE

Figure D-2b - Return Periods for Maximum Sustained Winds

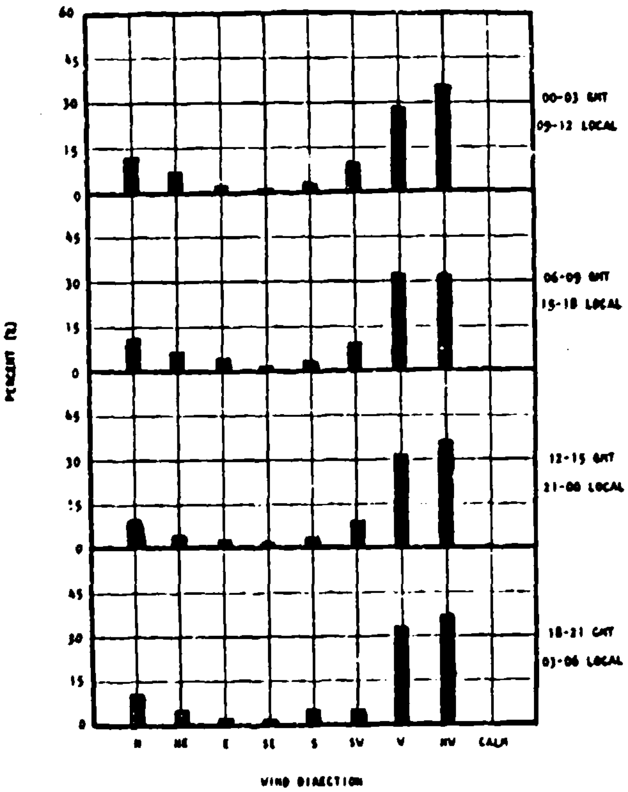


Figure D-2c - Wind Direction - Diurnal Variations

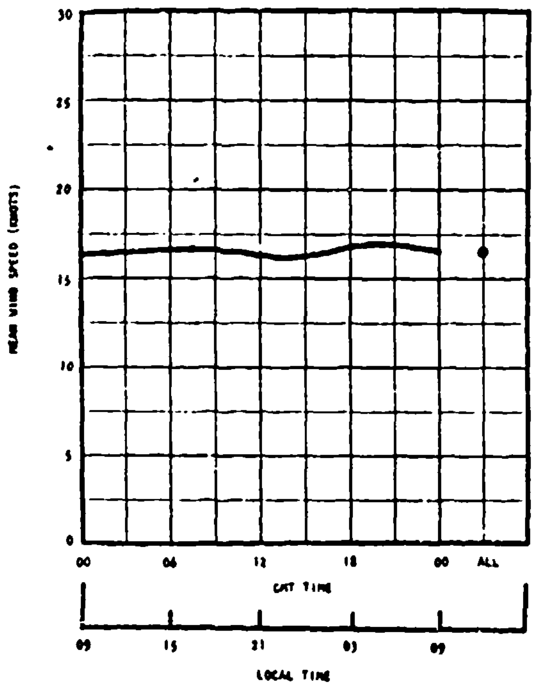


Figure D-2d - Mean Wind Speed - Diurnal Variation

NOT AVAILABLE

Figure D-2e - Gale Persistence

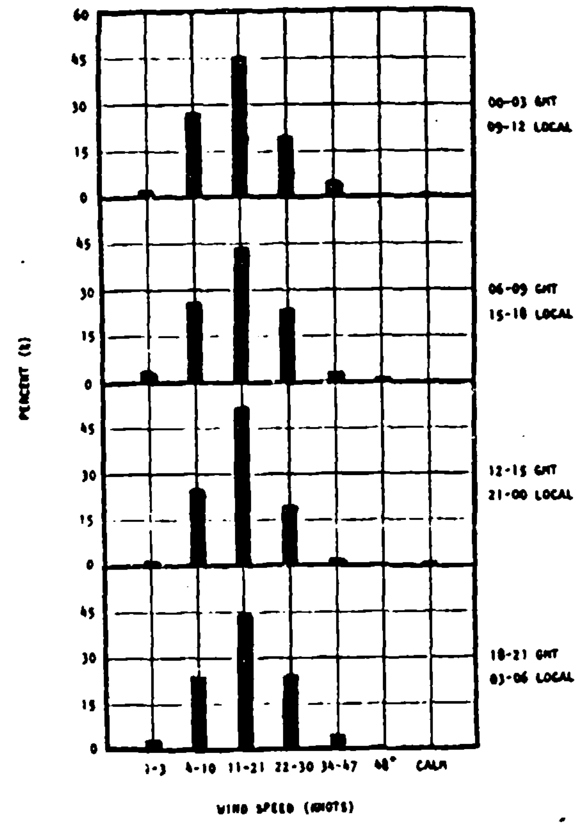


Figure D-2f - Wind Speed - Diurnal Variation

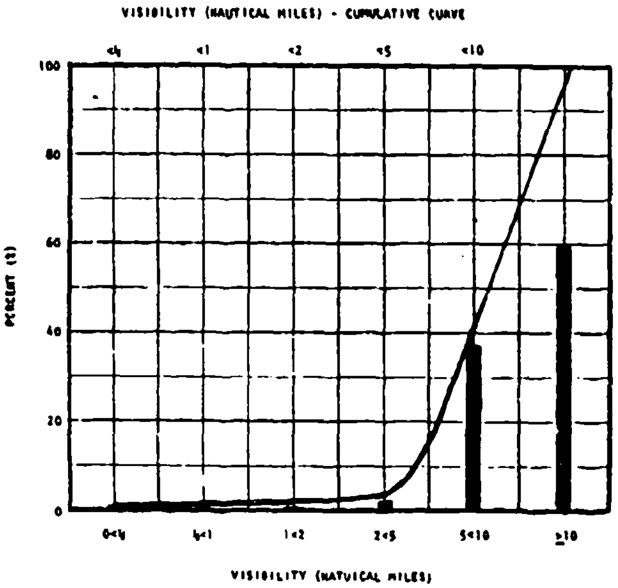


Figure D-3a - Visibility - Cumulative Distribution

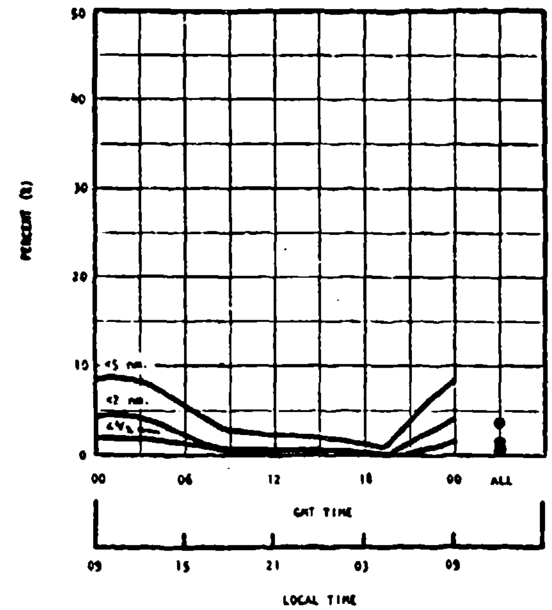


Figure D-3b - Visibility - Diurnal Variation

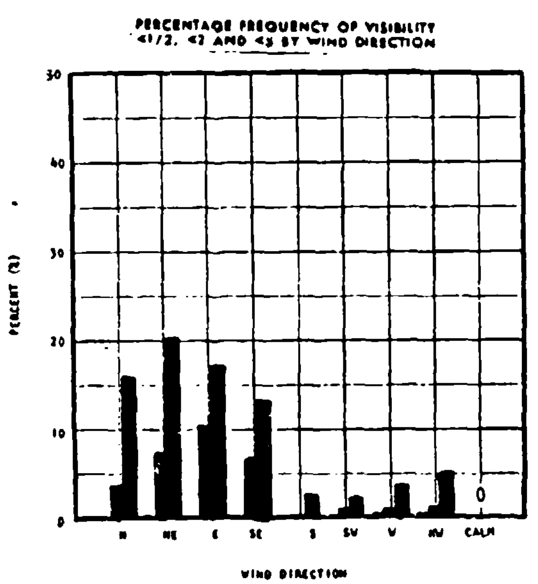


Figure D-3c - Visibility by Wind Direction

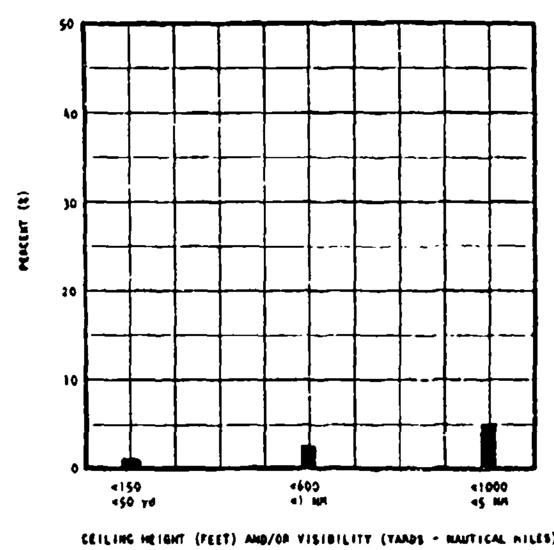


Figure D-3d - Low Visibility and/or Ceiling Height

NOT AVAILABLE

Figure D-3e - Visibility Persistence

Ⓓ 39°N , 129°E

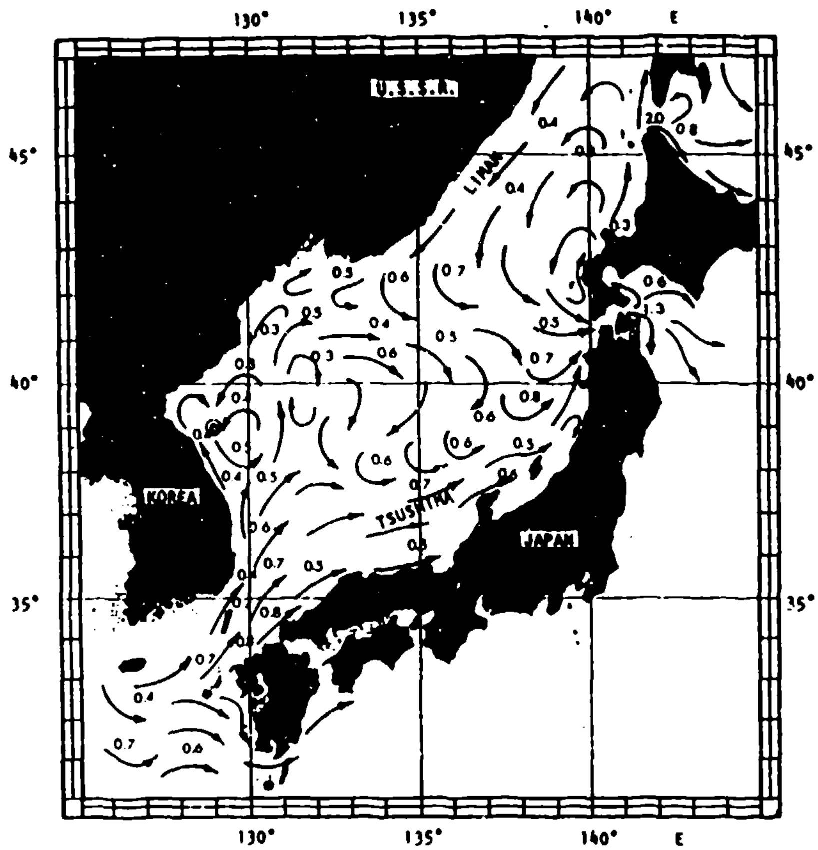


Figure D-4a - Mean Surface Current Speeds and Prevailing Directions

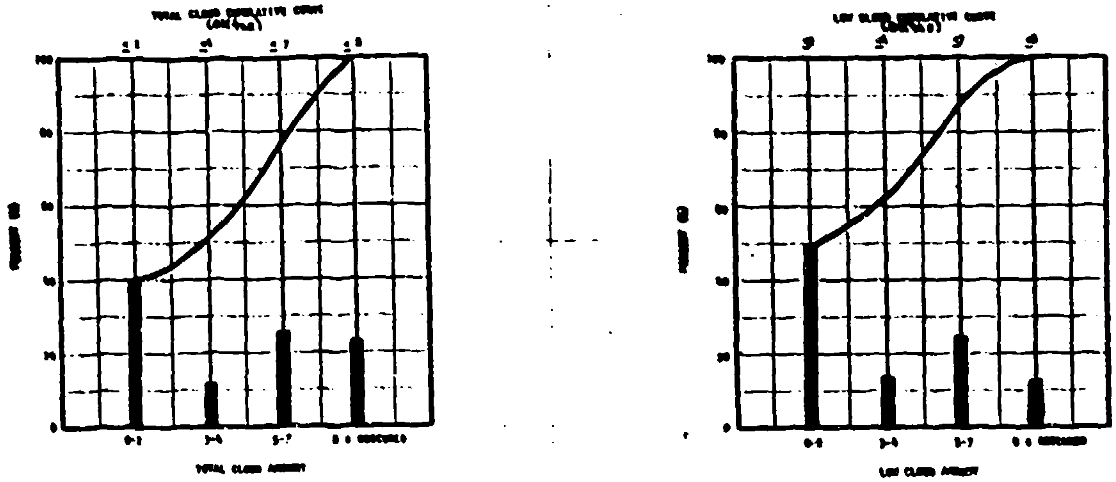


Figure D-5a - Cloud Amounts - Cumulative Distribution

NOT AVAILABLE

Figure D-5b - Mean Cloud Amounts

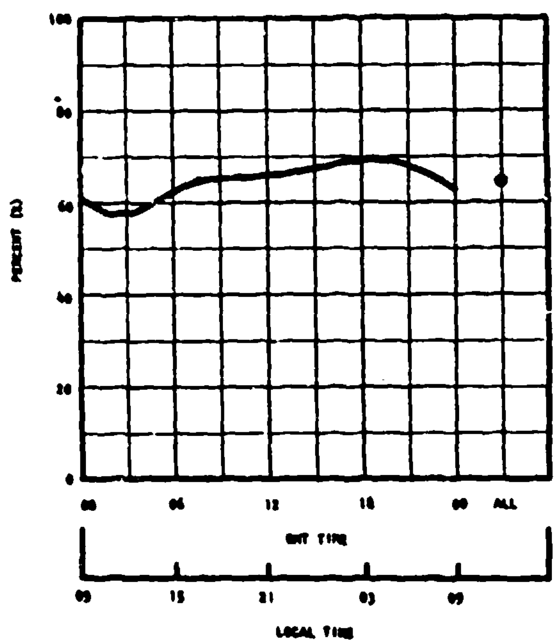


Figure D-5c - Good Cloud Conditions - Diurnal Variation

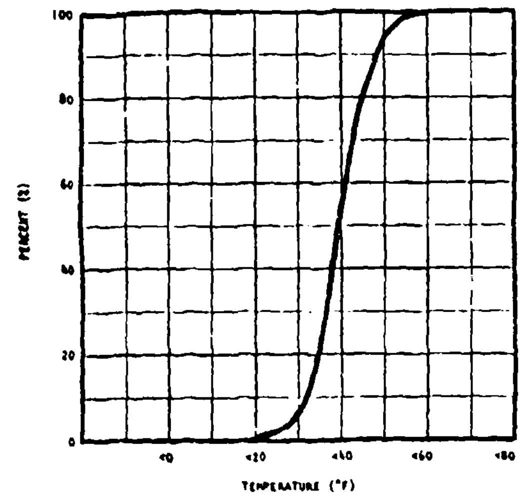


Figure D-6a - Air Temperature - Cumulative Distribution

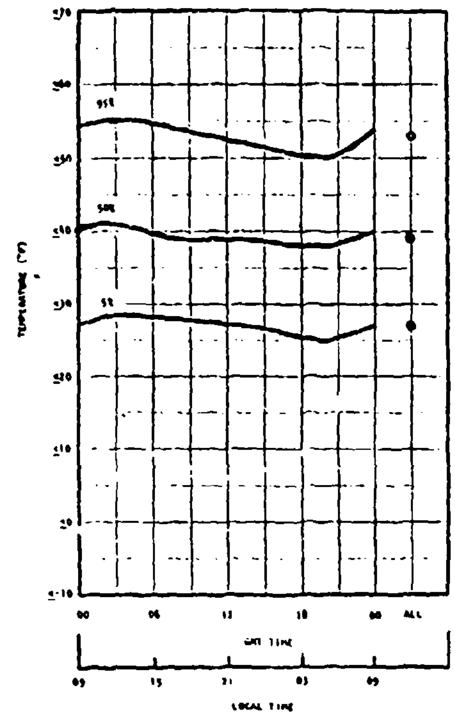


Figure D-6b - Air Temperature - Diurnal Variation

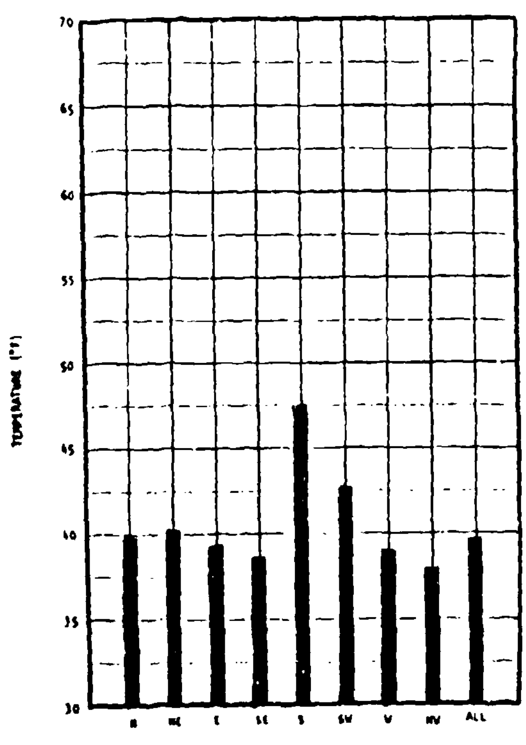


Figure D-6c - Mean Air Temperature by Wind Direction

PERCENTAGE FREQUENCY OF
SUB-FREEZING TEMPERATURES

Wind Speed	MAR	JUNE	SEPT	DEC
22-33	4.0	0.0	0.0	9.0
≥ 34	1.0	0.0	0.0	3.0

(SEE NEXT PAGE)

Figure D-6d - Air Temperature and Gales

Figure D-6e - Sea Surface Temperature

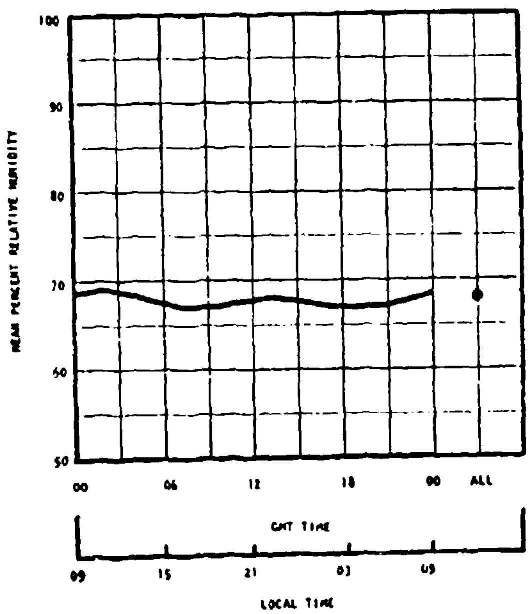


Figure D-6f - Relative Humidity Diurnal Variation

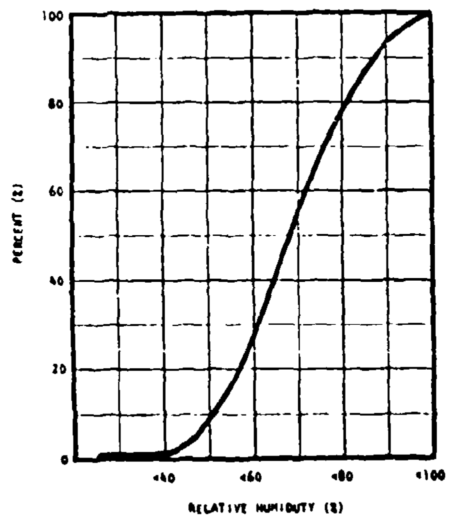


Figure D-6g - Relative Humidity - Cumulative Distribution

(5) 39°N , 129°E

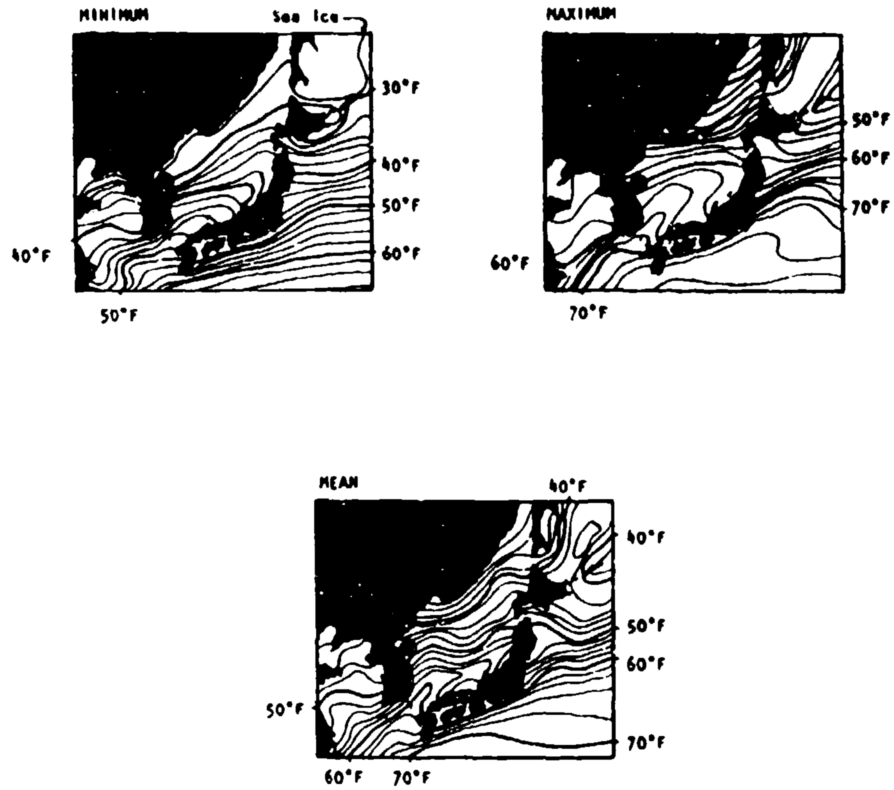


Figure D-6e - Sea Surface Temperature*

*Data of the form described in Appendix J was not available. Instead, contours of minimum, maximum, and mean temperatures are presented.

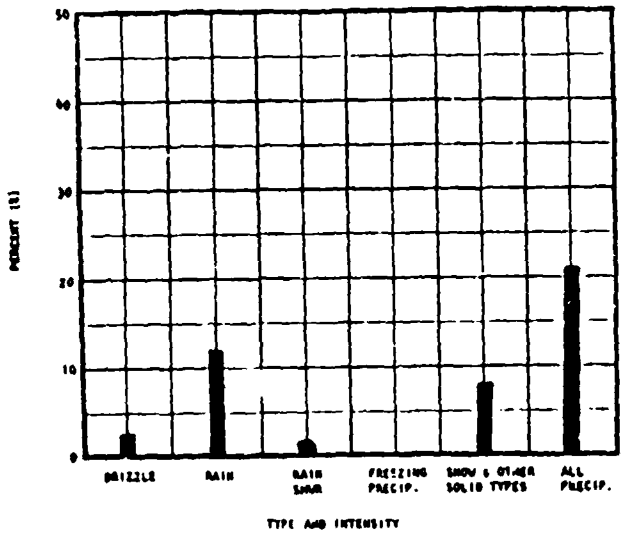


Figure D-7a - Precipitation by Type

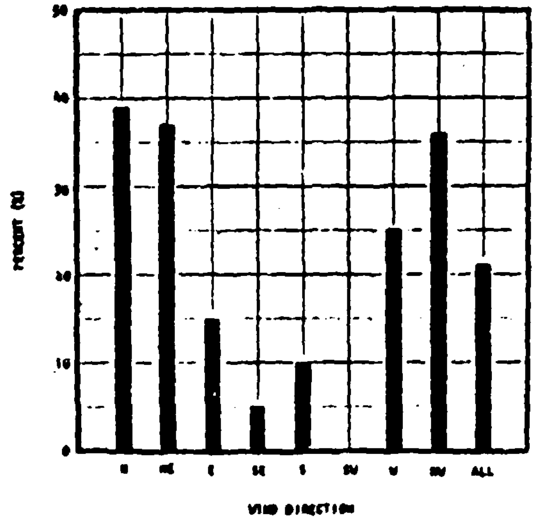


Figure D-7b - Precipitation by Wind Direction

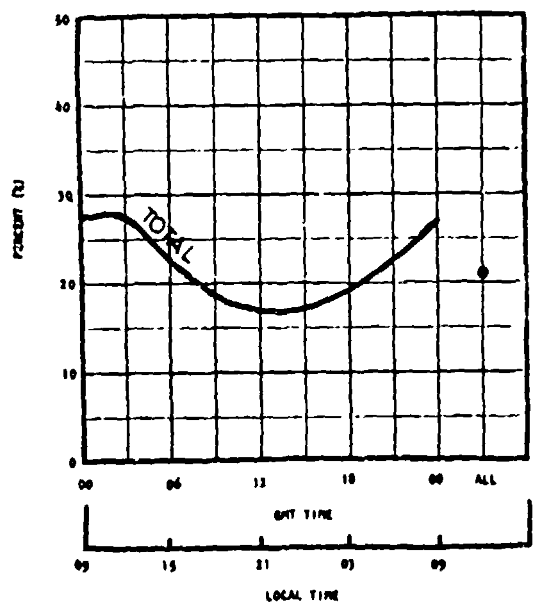


Figure D-7c - Precipitation - Diurnal Variation

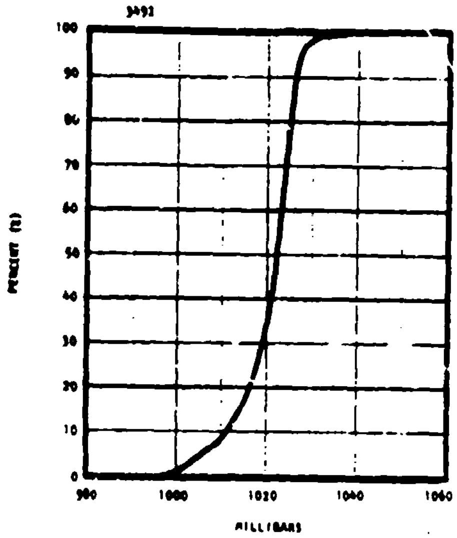


Figure D-8a - Sea Level Pressure -
Cumulative Distribution

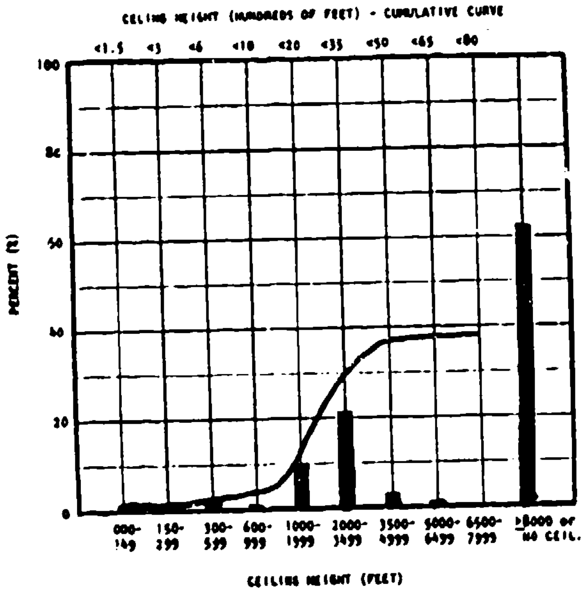


Figure D-9a - Ceiling Height

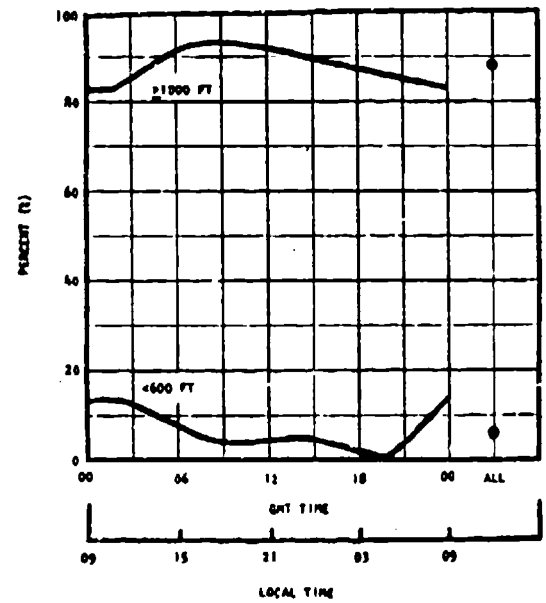


Figure D-9b - Ceiling Height - Diurnal Variation

NEGLIGIBLE OCCURRENCE
OF FOG REPORTED

Figure D-10a - Fog versus
Wind Direction

NEGLIGIBLE OCCURRENCE
OF FOG REPORTED

Figure D-10b - Fog versus
Air - Sea Temperature Difference

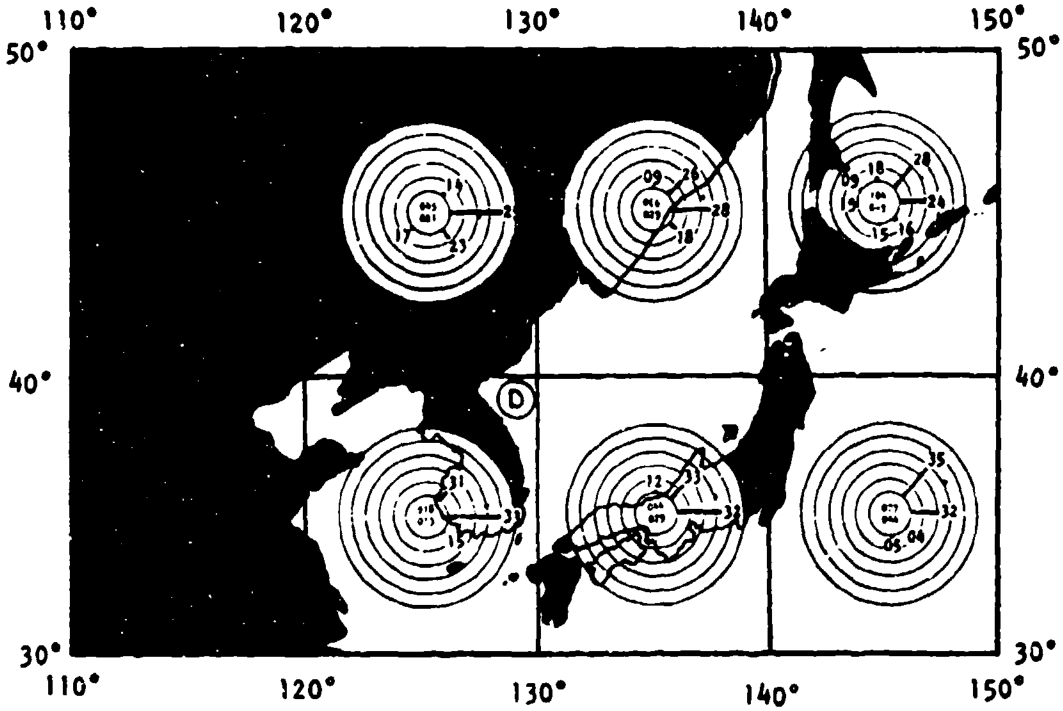


Figure D-11a - Low Pressure Centers

NO OCCURRENCES REPORTED

Figure D-11b - Extratropical Cyclones

NO OCCURRENCES REPORTED

Figure D-11c - Thunderstorms

NO OCCURRENCES REPORTED

Figure D-12a - Concentration

Figure D-12b - Icebergs

NOT AVAILABLE

Figure D-13a - Percentage frequency
of moderate and severe potential
for superstructure icing

APPENDIX E

MARINE CLIMATOLOGY OF THE GULF OF ADEN:

12°N, 43°30'E (OFF SAUDI ARABIA)

PART I. GENERAL MARINE CLIMATOLOGY OF THE GULF OF ADEN: 12°N, 46°30'E (OFF SAUDI ARABIA)

1. A general climatology for the oceanographic area defined by 12°N, 46°30'E (off southern Saudi Arabia) is developed. The area is denoted as Location E on Figure E-1 and is considered important to U.S. Naval operations since it is a principal sea route from a major source of petroleum for the western world. The prime data sources are References 5, 13, 14, 15, and 16. Emphasis is placed on the area about the location in the Gulf of Aden, but references to adjoining seas, e.g., the Red and Arabian seas are made where appropriate.

2. Location E lies southwest of the Red Sea and is among the hottest regions on earth. Rainfall is very light, but the humid, tropical air makes the climate oppressive during most of the year. The geographical location of the area between the African and Asian continents means that the weather is affected by seasonal monsoons from these areas and consequently, can vary throughout the year despite the region's proximity to the Equator. The minimal amount of rainfall in this area occurs during short storms. The most turbulent time of year is in summer (July) when the mean seasonal sea level pressure is at a minimum of 1002.5 millibars. Figure E-2 illustrates the seasonal variation in mean sea level pressure.

3. Throughout the year, winds in the Gulf of Aden are governed by the monsoons in the Arabian Sea and the Indian Ocean. Between October and May, the northeast monsoon prevails and the winds assume a westward (that is, from the east and towards the west) or west-southwestward direction. Generally, the winds range between calm and 16 knots, with higher winds from January to March (over 17 percent between 17 and 27 knots). From June to September, steady winds from the south-to-southwest-to-west prevail, blowing strongly at times out of the Red Sea eastward to Suqutra Island. Near the African coast there are, during this season, occasional violent north-northeastward land squalls which last about an hour and always occur between midnight and daybreak. The highest average wind speeds at Location E occur in summer (July) with a value of 11 knots. The lowest seasonal average wind speed occurs in fall (October) with a value of 8.7 knots. The interval between the monsoons is marked by light and variable winds which

are frequently interrupted by rain and lightning. During the beginnings and endings of these transition periods, it is not unusual to have brief but violent rain and thunder storms. The northeast monsoon brings lighter wind and fair weather in the winter, and the southwest monsoon can be very strong and accompanied by thick, hazy weather. Along the southern coast of the Arabian peninsula the wind is often light and variable.

The monsoons and atmospheric pressure can cause fluctuations in water level by as much as 2 feet between the low in summer and a high in winter.

4. Surface current speeds and directions throughout the area are also influenced by the northeast and southwest monsoons. Figure E-1 shows the seasonal variation in currents flowing about Location E. Strong currents, up to 2.5 knots, have been observed in the strait on the eastern end of the Gulf of Aden. From October through April, the current in the Gulf is southwestward and ranges in speed from 0.2 to 1 knot. During the rest of the year, the current runs northeastward at about 1 knot near the middle of the Gulf and Location E and up to 2 knots off the Arabian coast. While this latter speed may even reach 3 knots, the current invariably becomes weaker in October, and its direction changes to southwestward.

5. Sea and swell conditions flowing northeastward and eastward are common during the months of October through May when the northeast monsoon prevails. From June through September, the southwest monsoon dominates conditions resulting in northward and northeastward seas and swells. During the summer, the seas at Location E are calm less than 14 percent of the time and waves of heights of 7 feet or greater are observed 16 percent of the time. In summer, waves as high as 13 to 16 feet with periods up to 13 seconds or more have been observed. The mildest waves occur in spring with only 3.9 percent of observations of 7 feet or more. Figure E-3 shows the seasonal variation of wave heights at Location E. Some swell is expected during the monsoon seasons.

Turbulent weather occurs uniformly throughout the year, though the summer (July) evinces the harshest conditions with 10 percent of waves being 7 feet in height and 6 percent being over 8 feet in height at Location E.

6. Rainfall in the region, as previously mentioned, is very light. The meager amount of rainfall, perhaps only a few inches a year, may occur with the infrequent thunderstorms observed throughout the year.

7. Fog occurs rarely at Location E. Haze is also infrequent, except in summer, when observations indicate its presence 12.5 percent of the time.

8. The mean annual temperature recorded at land stations on the Gulf of Aden is 86°F, which is the highest on earth. Near Berber, Somalia, the average daily maximum summer temperature reaches 107°F with a record high of 117°F and a mean low of 72°F recorded in June. At Location E, the air temperature can reach and exceed 100°F in summer, when the dry northward winds prevail. In winter, the higher temperatures are about 10 degrees less than in summer. Mean daily temperatures are 77°F in winter, 82°F in spring, 86°F in summer, and 84°F in fall. Mean relative humidity ranges between 76 percent in winter, 81 percent in spring, 77 percent in summer, and 74 percent in the fall. Without doubt, the climate at Location E is always sultry and oppressive.

9. Maximum sea surface temperatures in fall are over 89°F. The maximum sea surface temperature the rest of the year at Location E is at least 82°F.

10. Visibility is generally good in the Gulf of Aden most of the year. Exceptionally good visibility is observed for 1 out of 4 to 6 days, except in July when it is observed 1 out of 10 days. Summer dust storms at sea, which occur from May to August, reduce visibility significantly. These storms always come from the north or northwest and arrive with little or no forewarning. Visibility is generally low in summer on the eastern waters of the Gulf bordering the Arabian Sea.

Monthly charts show visibility declining regularly from a high of 96 percent for more than 10 nautical miles in November, the clearest month, to only 48 percent greater than 10 nautical miles during July, the worst month. Also during July, 37 percent of visibility is between 5 and 10 nautical miles, 4 percent between 2 and 5 nautical miles, 10 percent between 1 and 2 nautical miles and less than 1 percent less than 1 nautical mile.

11. The maximum number of hours of daylight is about 13 hours which occurs in June. The minimum number of hours of daylight which occurs in late December, is slightly more than 10 hours.

12. Earthquakes are relatively infrequent, though small shocks have been reported in the western part of the Gulf of Aden. Tsunamis can be caused

by these shocks and by shocks as far away as Iran and Pakistan. No eye-witness reports of tsunamis are available, however, possibly due to the sparse and generally illiterate population found in the region. Many spectacular and unusual forms of bioluminescent display have been observed in the Gulf of Aden. A very peculiar and spectacular type of display consists of large luminescent bubbles rising from the depths and bursting into bright, white flashes at the surface. The luminescence can be generated by the pulsations of a vessel's engines. Bright displays can be triggered by a radar beam and will disappear when the radar is turned off. Luminescence caused by a beam of light, however, remains for a certain time after the light is turned off. Refraction phenomena, such as mirages, are common in the Gulf of Aden due to hot winds from the desert.

Since the neighboring Red Sea is notorious for harboring venomous fish, rays, and invertebrates such as stonefish, stingrays, Moray eels and sharks, Gulf of Aden waters might be considered dangerous to the safety of men.

13. The mean salinity of the sea surface in this region is 36 parts per thousand and remains almost constant throughout the year.

14. Water depth about Location E is between 500 and 1000 fathoms, with generally shallower water to the west and along the shores, and deeper water toward the Arabian Sea in the east.

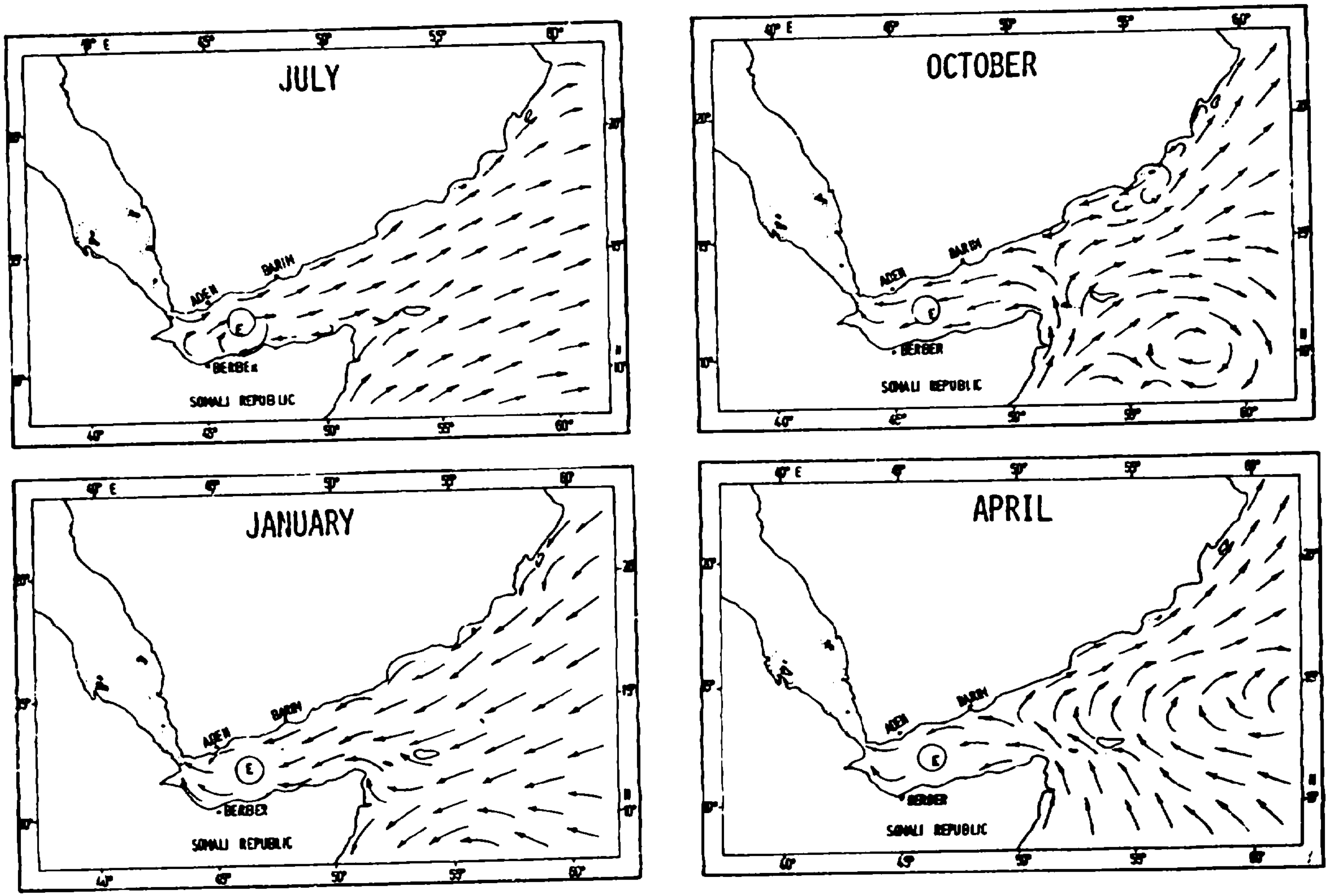


Figure E-1 - Generalized Ocean Currents for the Gulf of Aden

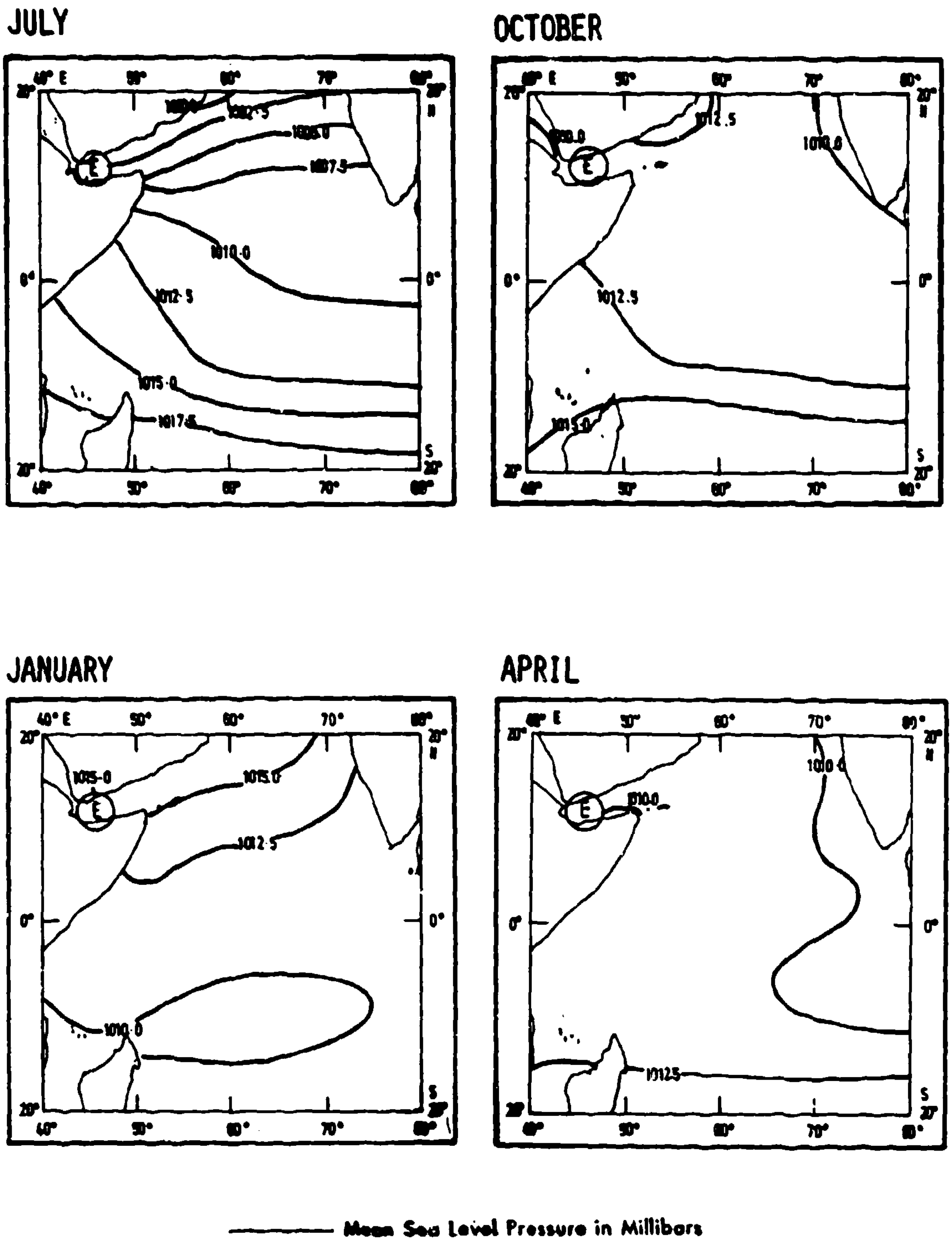


Figure E-2 - Seasonal Mean Sea Level Pressures

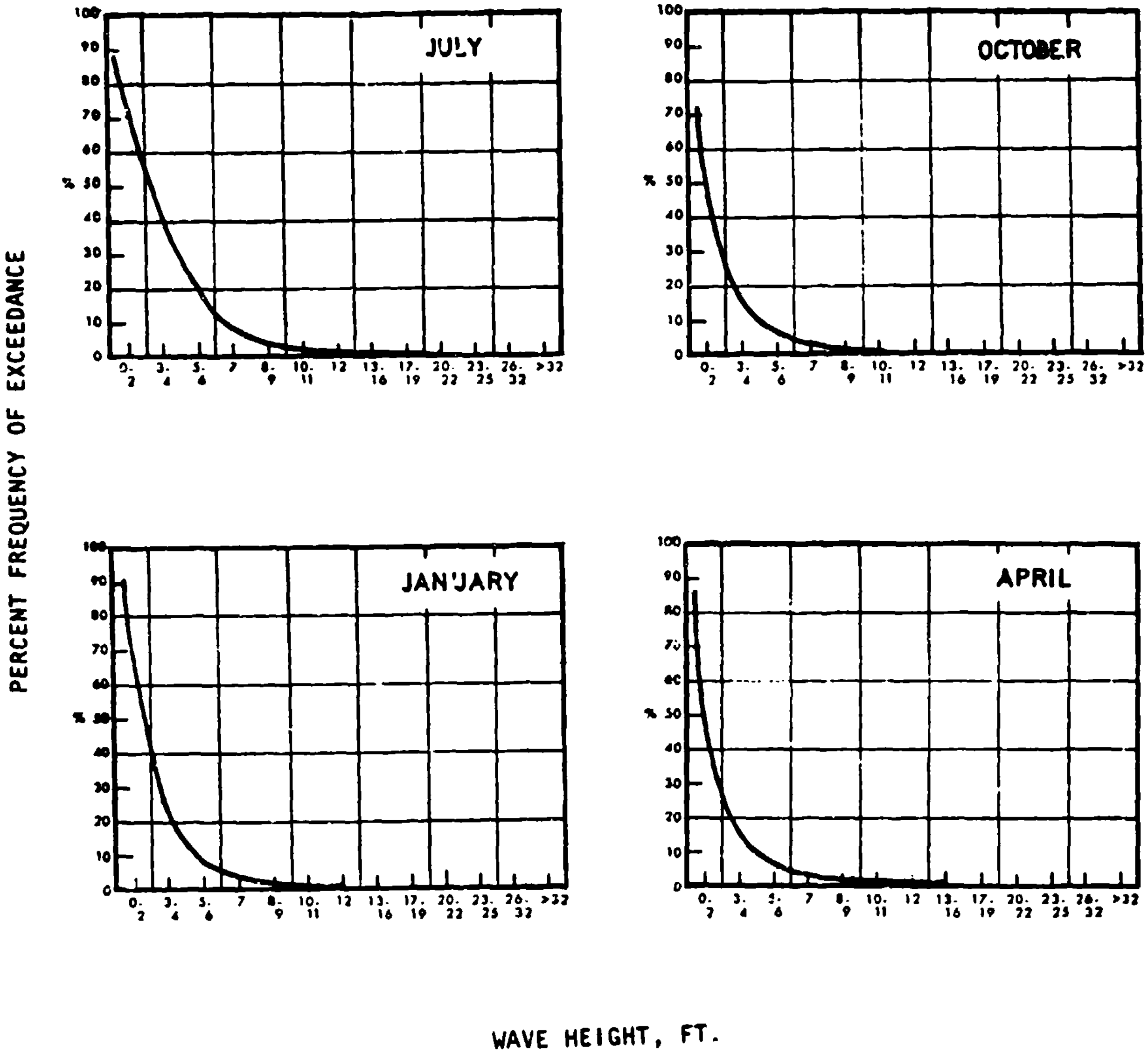
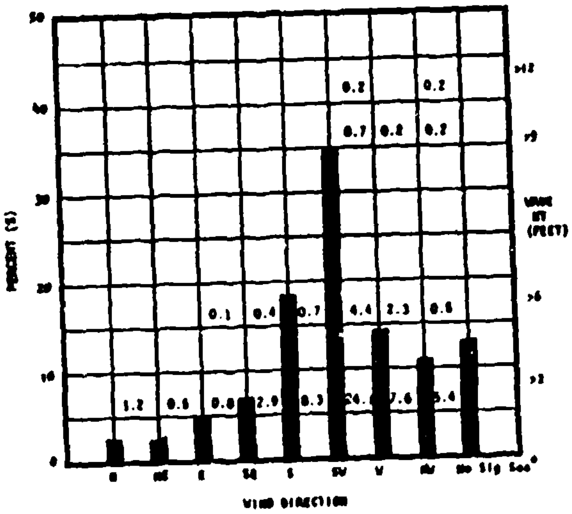


Figure E-3 - Seasonal Wave Height Exceedances

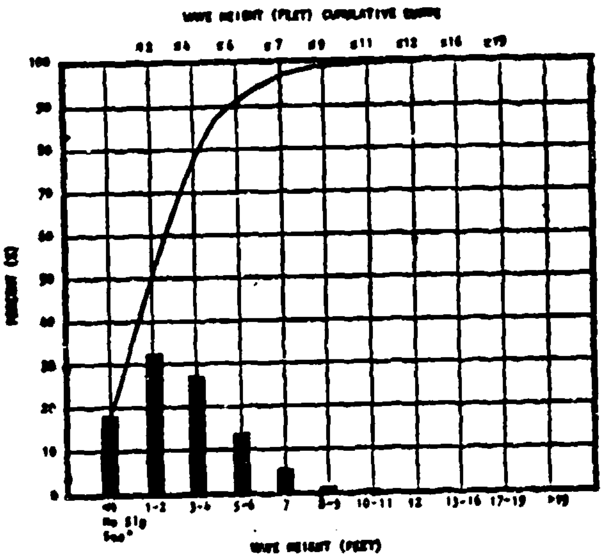
PART II. SUMMER (JULY) CLIMATOLOGY OF THE GULF OF ADEN: 12° N, 46°30'E (OFF SAUDI ARABIA)

The following data graphs are derived primarily from Volume 1 of the East African and Selected Island Coastal Marine Areas (Area 6) of Reference 5 for the worst wind/wave season, July. Figure E-4a is adopted from Reference 13.



*No Significant Sea. Either wave conditions were calm or the only wave observed was small wave.

Figure E-1a - Sea Height by Wind Direction



*No Significant Sea. Either wave conditions were calm or the only wave observed was small wave.

Figure E-1b - Sea Height - Cumulative Distribution

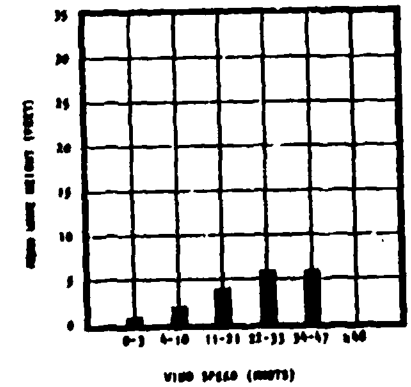


Figure E-1c - Mean Sea Height by Wind Speed

NOT AVAILABLE

Figure E-1d - Swell Height by Direction

NOT AVAILABLE

Figure E-1e - Swell Height - Cumulative Distribution

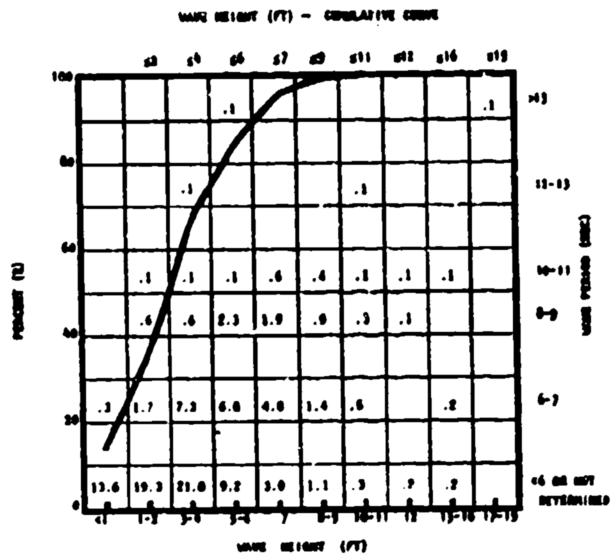


Figure E-1f - Wave Height and Period

NOT AVAILABLE

Figure E-1g - Return Periods for High Waves

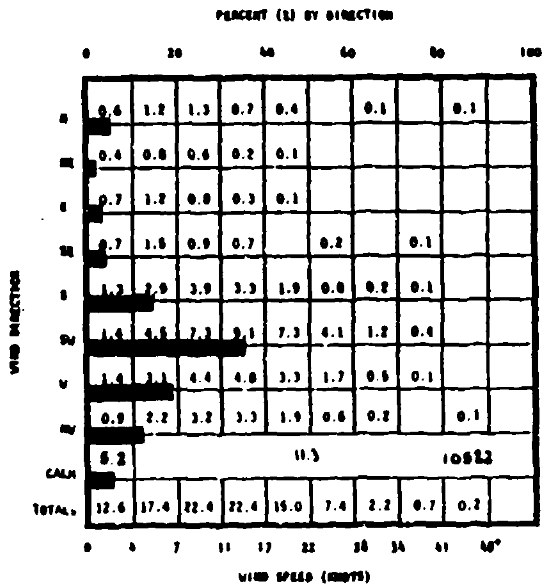


Figure E-2a - Wind Speed by Direction

NOT AVAILABLE

Figure E-2b - Return Periods for Maximum Sustained Winds

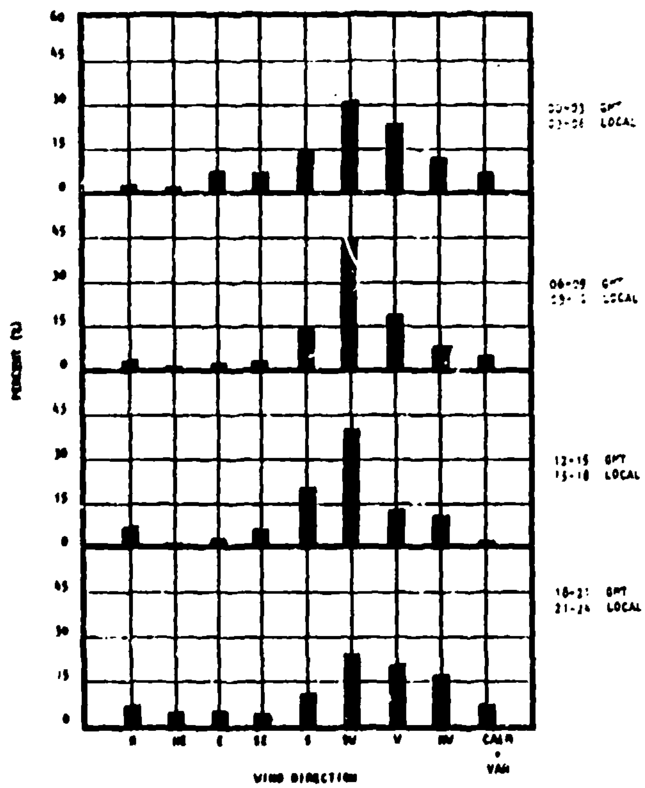


Figure E-2c - Wind Direction - Diurnal Variations

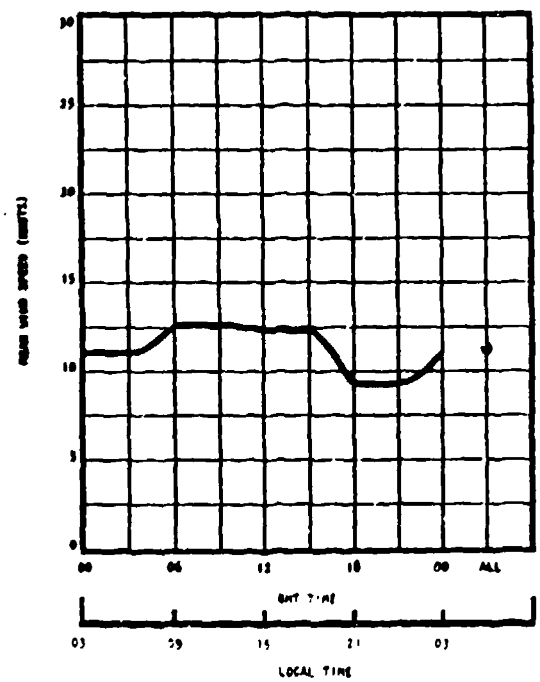


Figure E-2d - Mean Wind Speed Diurnal Variation

NOT AVAILABLE

Figure E-2e - Gale Persistence

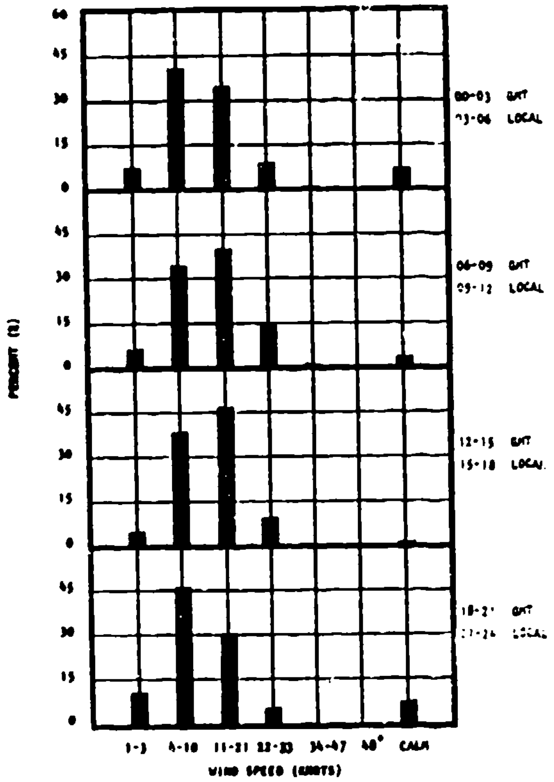


Figure E-2f - Wind Speed - Diurnal Variation

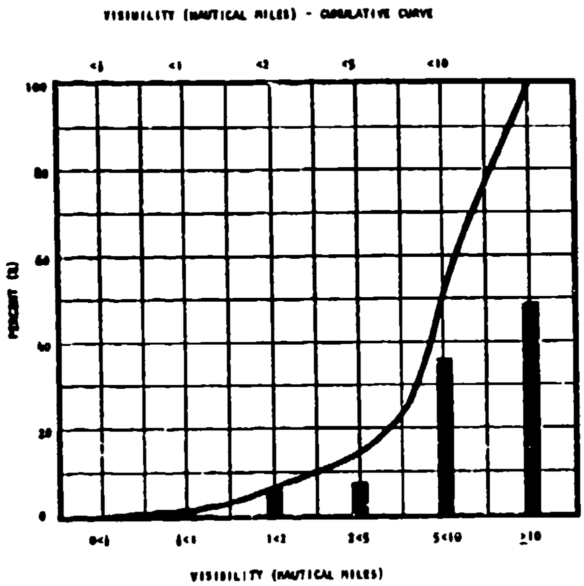


Figure E-3a - Visibility Cumulative Distribution

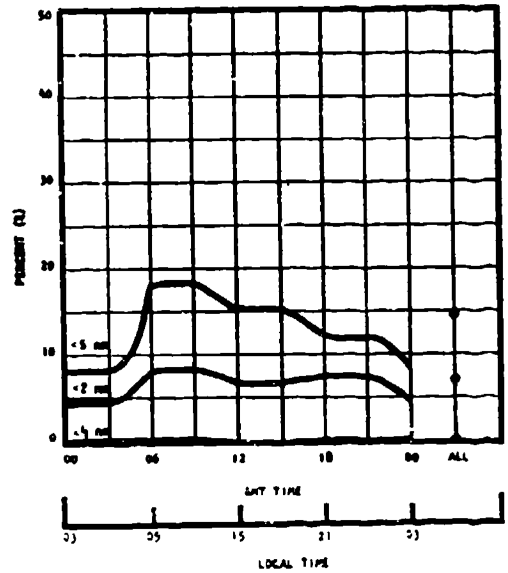


Figure E-3b - Visibility - Diurnal Variation

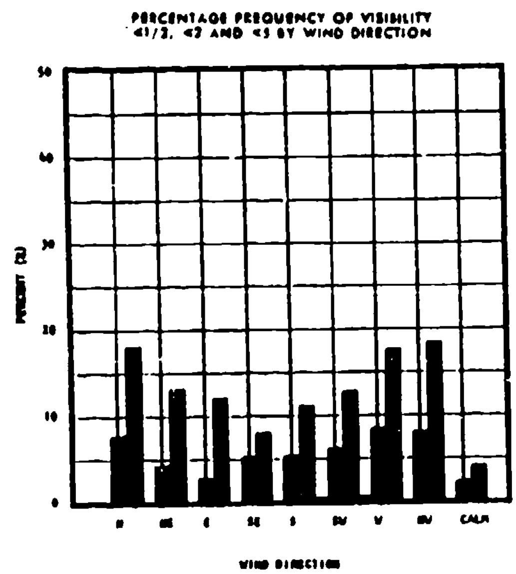


Figure E-3c - Visibility by Wind Direction

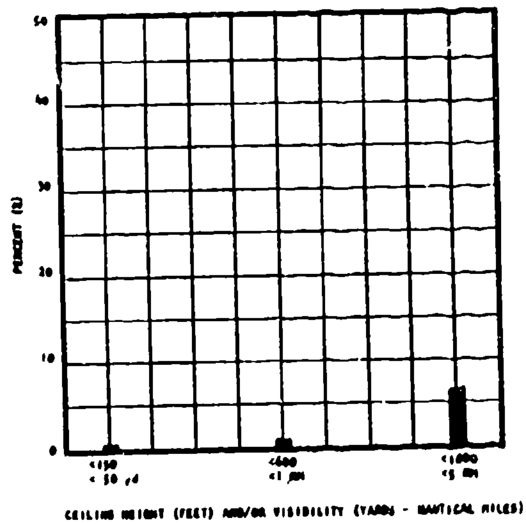


Figure E-3d - Low Visibility and/or Ceiling Height

NOT AVAILABLE

Figure E-3e - Visibility Persistence

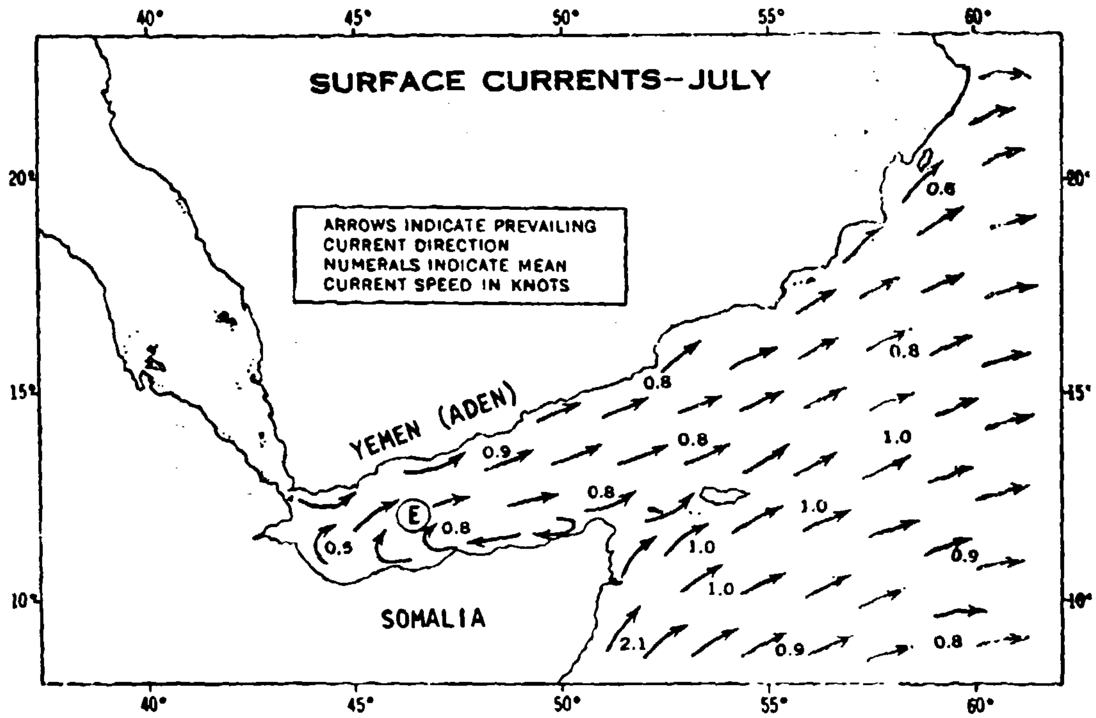
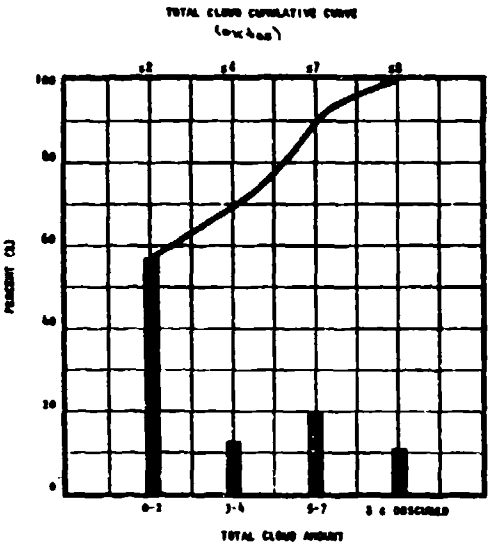


Figure E-4a - Mean Surface Current Speeds and Prevailing Directions



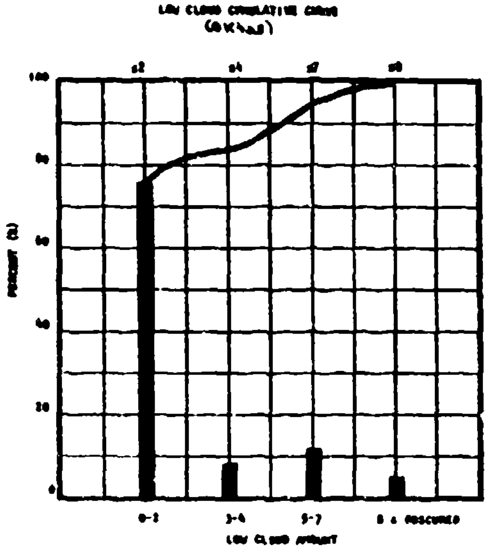


Figure E-5a - Cloud Amounts -
Cumulative Distribution

NOT AVAILABLE

Figure E-5b - Mean Cloud Amounts

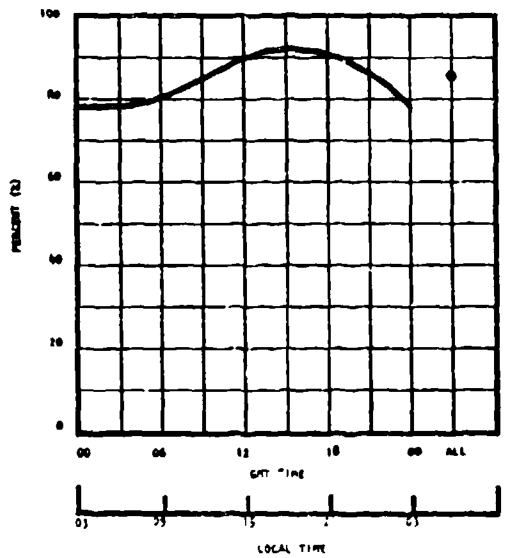


Figure E-5c - Good Cloud Conditions -
Diurnal Variation

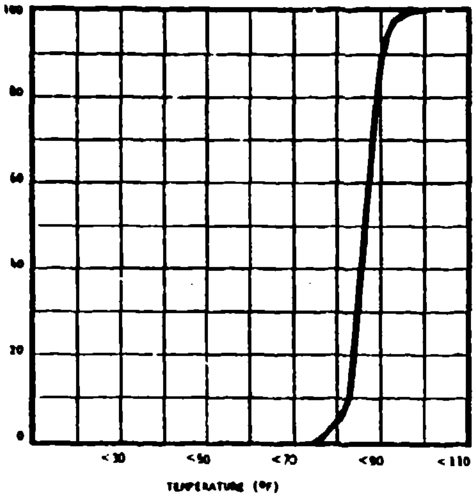


Figure E-6a - Air Temperature - Cumulative Distribution

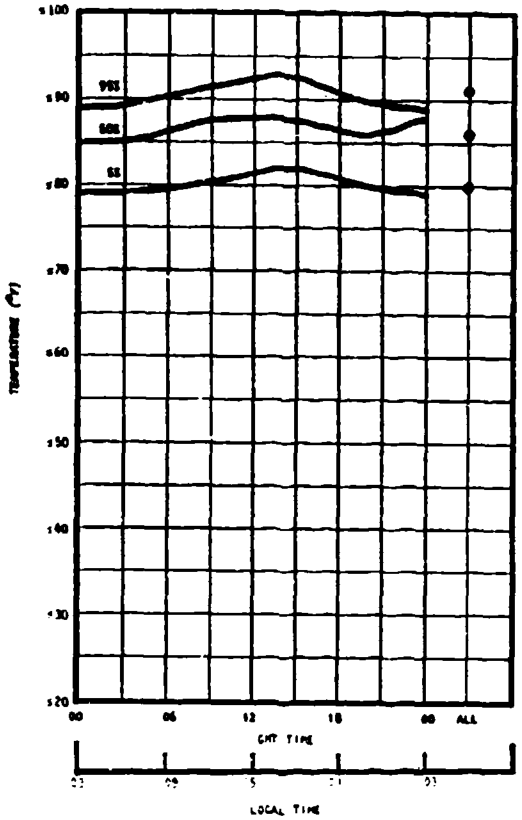


Figure E-6b - Air Temperature - Diurnal Variation

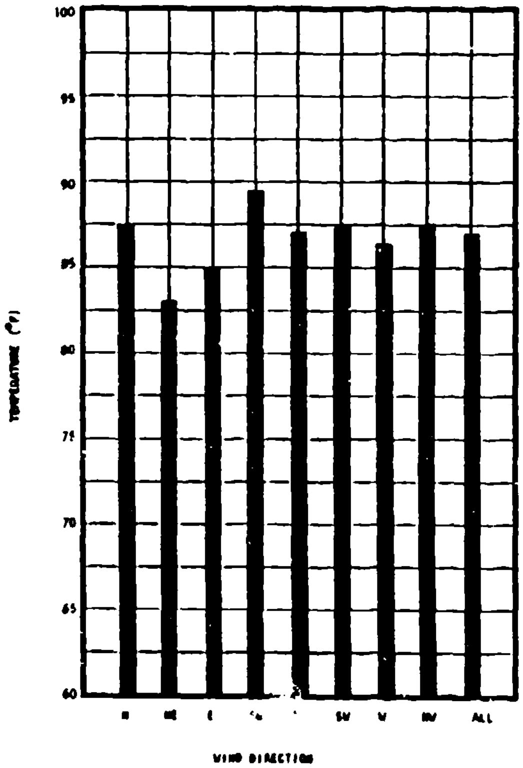


Figure E-6c - Mean Air Temperature by Wind Direction

NO OCCURRENCES

(SUB-FREEZING TEMP. OR GALES)

REPORTED

Figure E-6d - Air Temperature and Gales

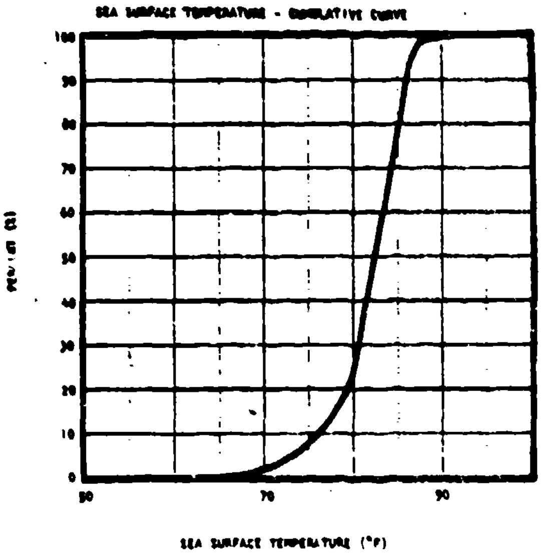


Figure E-6e - Sea Surface Temperature

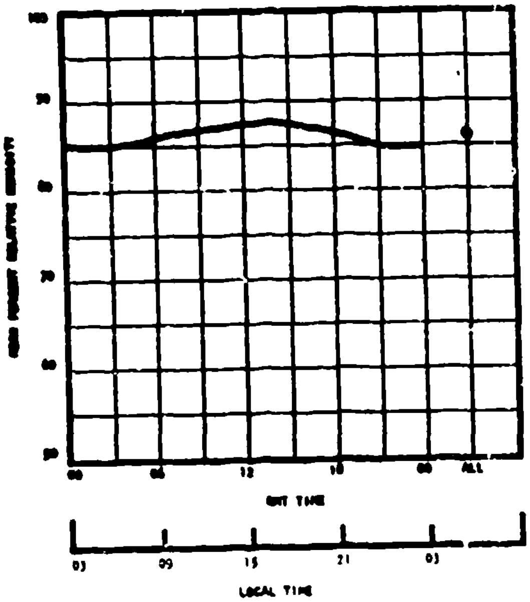


Figure E-6f - Relative Humidity - Diurnal Variation

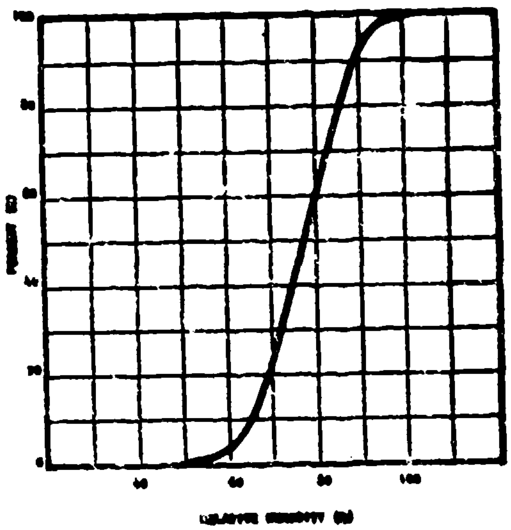


Figure E-6g - Relative Humidity Cumulative Distribution

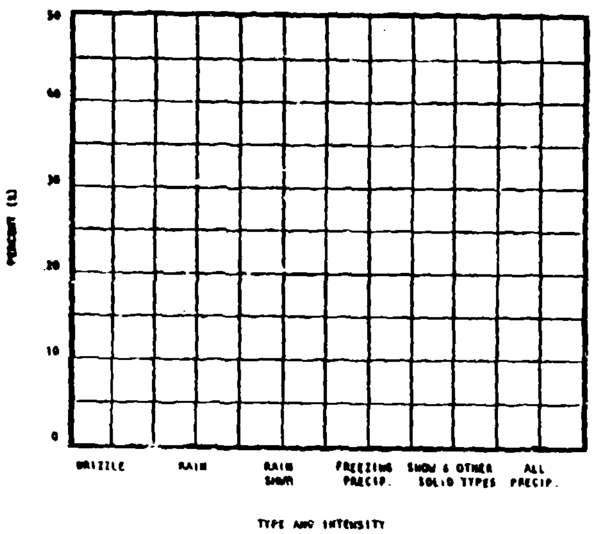


Figure E-7a - Precipitation by Type

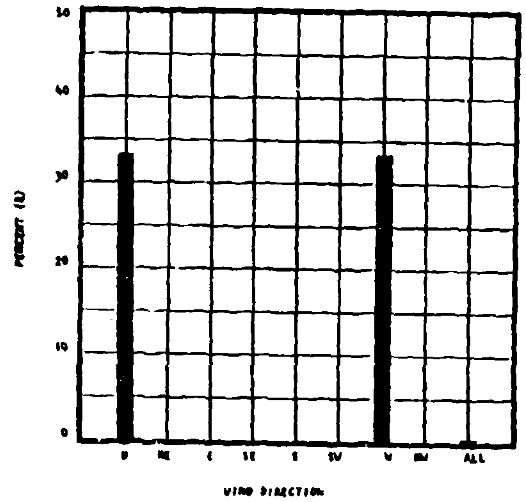


Figure E-7b - Precipitation by Wind Direction

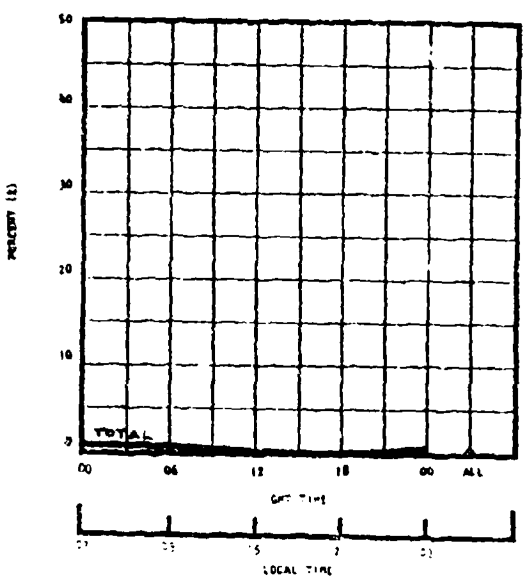


Figure E-7c - Precipitation - Diurnal Variation

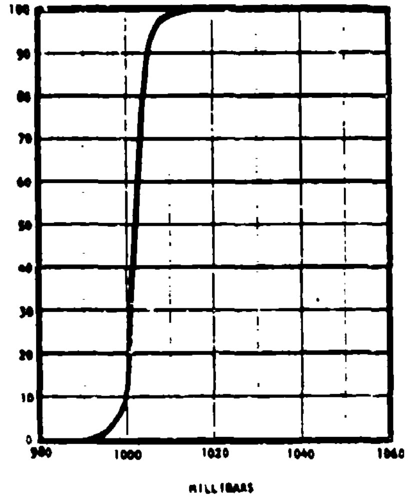
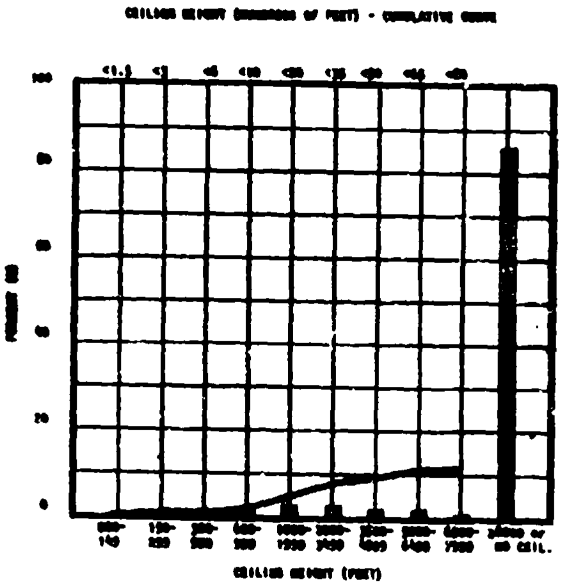


Figure E-8a - Sea Level Pressure - Cumulative Distribution



F E-9a - Ceiling Height

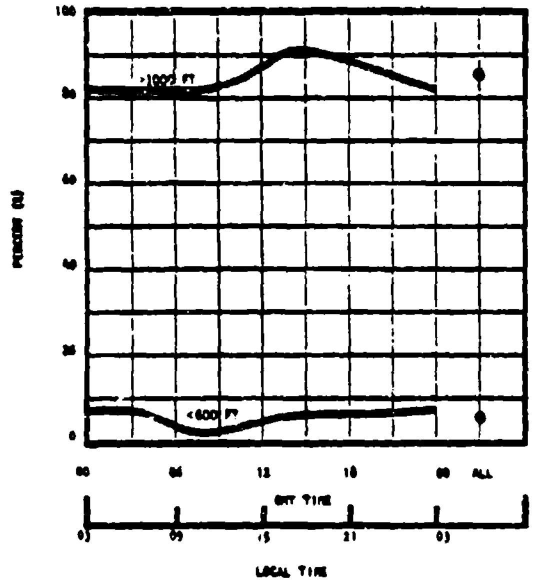


Figure E-9b - Ceiling Height - Diurnal Variation

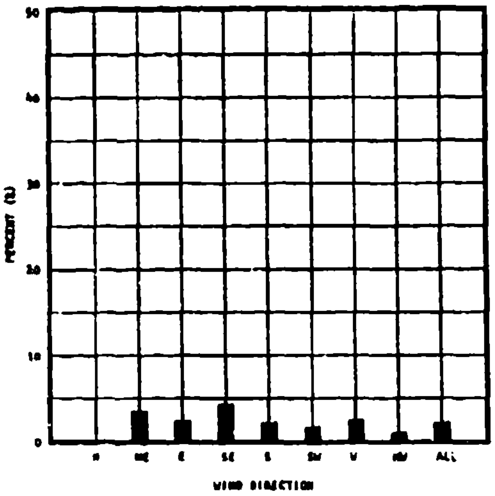


Figure E-10a - Fog versus
Wind Direction

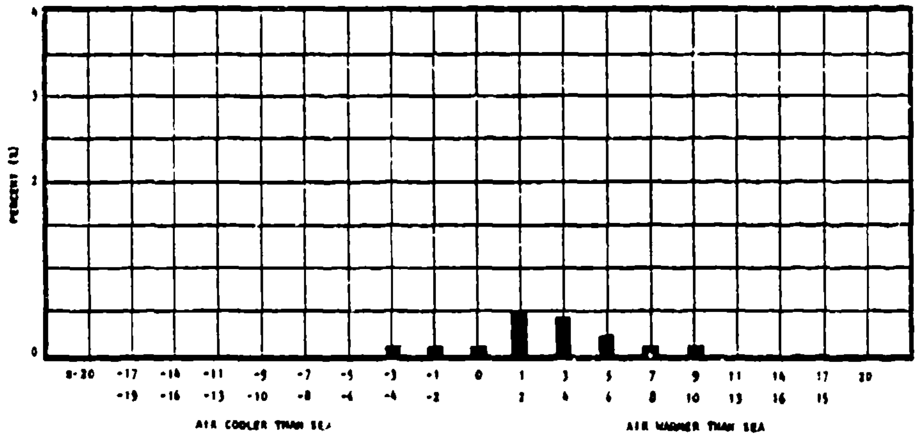


Figure E-10b - Fog versus
Air - Sea Temperature Difference

NOT AVAILABLE

Figure E-11a - Low Pressure Centers

NO OCCURRENCES REPORTED

Figure E-11b - Tropical Cyclones

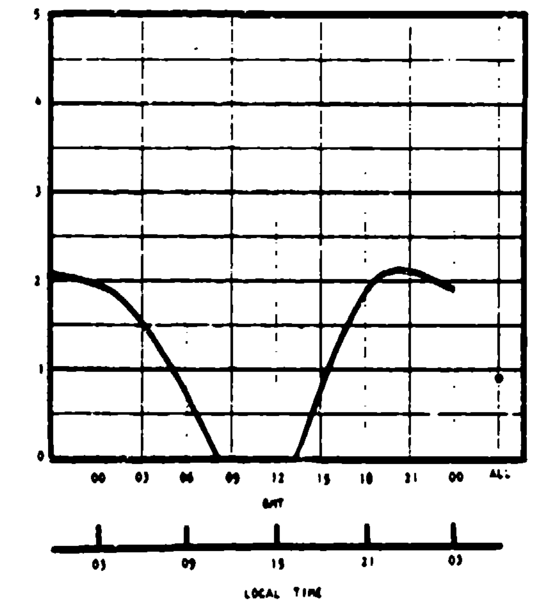


Figure E-11c - Thunderstorms

NO OCCURRENCES REPORTED

Figure E-12a - Concentration

Figure E-12b - Icebergs

Figure E-13a - Percentage Frequency of moderate and severe potential for superstructure icing

APPENDIX F

MARINE CLIMATOLOGY OF THE SOUTHEASTERN NORTH ATLANTIC:

9°30'N, 16°0'W (OFF GUINEA)

PART I. GENERAL MARINE CLIMATOLOGY OF THE SOUTHEASTERN NORTH ATLANTIC: 9°30'N, 16°0'W (OFF GUINEA)

1. A general climatology for the oceanographic area defined by 9°30'N, 16°0'W is developed. The area is denoted as Location F on Figure F-1 and is considered important to U.S. Navy operations because of its strategic location in the major European sea route to South Africa and to Australia. The prime data sources are References 3, 5, 6, 17, and 18.

2. Due to its proximity to the Equator, the climate at Location F is generally hot and tropical in nature. It exhibits two seasons: one dry (from about December to April) and the other wet (from about May to November) due to the seasonal tradewinds. The dry season corresponds with winter, having cooler temperatures. In the dry season, the "harmattan" blowing from the desert in the northeast controls the weather.

3. The primary current, see Figure F-1, is along the coast in a southeastward direction, with a mean speed of less than 1 knot. Further south, the current shifts westward and picks up speed as it forms the southern loop of the North Atlantic current. There are no significant seasonal changes. Barometric pressure is nearly constant at about 1012 millibars throughout the year, see Figure F-2.

4. Annually at Location F, approximately 44 percent of winds are between 7 and 16 knots. Mean wind speeds are 7 knots in winter (February), 7 knots in spring (May), 11 knots in summer (August), and a low 5 knots in fall (November). Winds are generally from a westerly to northerly direction from fall through spring and from a southerly to westerly direction in summer. Gale force winds of 34 knots or greater are rarely observed.

5. Generally the sea direction coincides with the wind direction, though swells from the south and southwest are sometimes observed. Figure F-3 indicates the seasonal variation of observed wave heights. Waves of 7 feet or less are observed 97 percent of time in winter and spring, 92 percent of time in summer, and 98 percent of time in fall. Wave periods are generally less than 9 seconds. The most severe wave ever observed at Location F was 20 to 22 feet in height and greater than 13 seconds in period and was observed in summer when the winds are generally highest.

6. The precipitation in this location is among the heaviest in the world, reaching 170 inches annually. Nearly all of the rainfall occurs during the wet season lasting from May to November. July and August are the rainiest months with precipitation observed about 20 percent of the time. The rainfall inland is less, about 80 inches per year.

7. The air temperature is fairly constant at Location F, averaging about 79°F with a lowest seasonal mean of 76°F occurring in winter and a highest seasonal mean of 81°F occurring in fall. In general, the warmer temperatures occur between spring and fall. The lowest temperatures as well as the greatest temperature drops (from 10 to 14°F), occur in winter. The inland climate is more variable, with a temperature range of 64°F to 104°F.

8. Fog occurs occasionally at Location F. Observations indicate 3 percent occurrence in winter, 2 percent in spring, and less than 1 percent in summer and fall. A more frequently observed weather phenomenon is haze which occurs in up to 7 percent of winter observations and is caused by the blowing of fine dust and sand particles out to sea by the harmattan. The mean cloud presence is 4.5 to 6.1 during the year (on a scale of 0 to 10, where 0 means clear skies and 10 means overcast).

9. Mean sea surface temperatures range between a high of 82°F in fall and a low of 76°F in spring. From spring to fall, mean temperatures remain above 80°F. Throughout the year, maximum temperatures remain about 84°F.

10. Visibility at Location F is poor during the dry season's harmattan haze (dust haze), reducing visibility to a mere mile for several days at a time.

The poorest general visibility occurs in spring when visibility of more than 10 nautical miles was recorded in about 71 percent of observations, 26 percent were between 5 and 10 nautical miles, 2 percent between 2 and 5 nautical miles, and 1 percent less than 1 nautical mile. The clearest season, fall, has visibility of more than 10 nautical miles for 80 percent of observations, while visibility of less than 5 miles occurred during about 2 percent of observations.

11. The maximum number of hours of daylight, occurring in June, is 12½ hours. The minimum number of daylight hours occurring in late December is 11½ hours.

12. At the location, water depth is no more than about 1000 fathoms. Eastward towards the Guinea coast a steep slope exists bringing the sea floor to shallow depths and westward the depth quickly drops to 2000 fathoms. Surface salinity remains about 34 parts per thousand throughout the year.

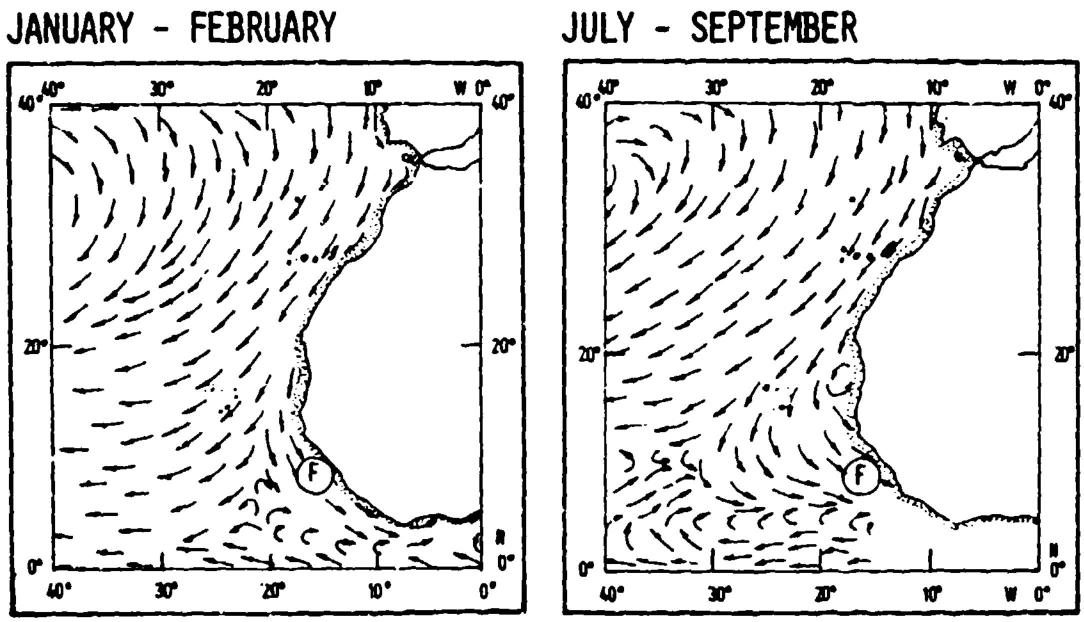
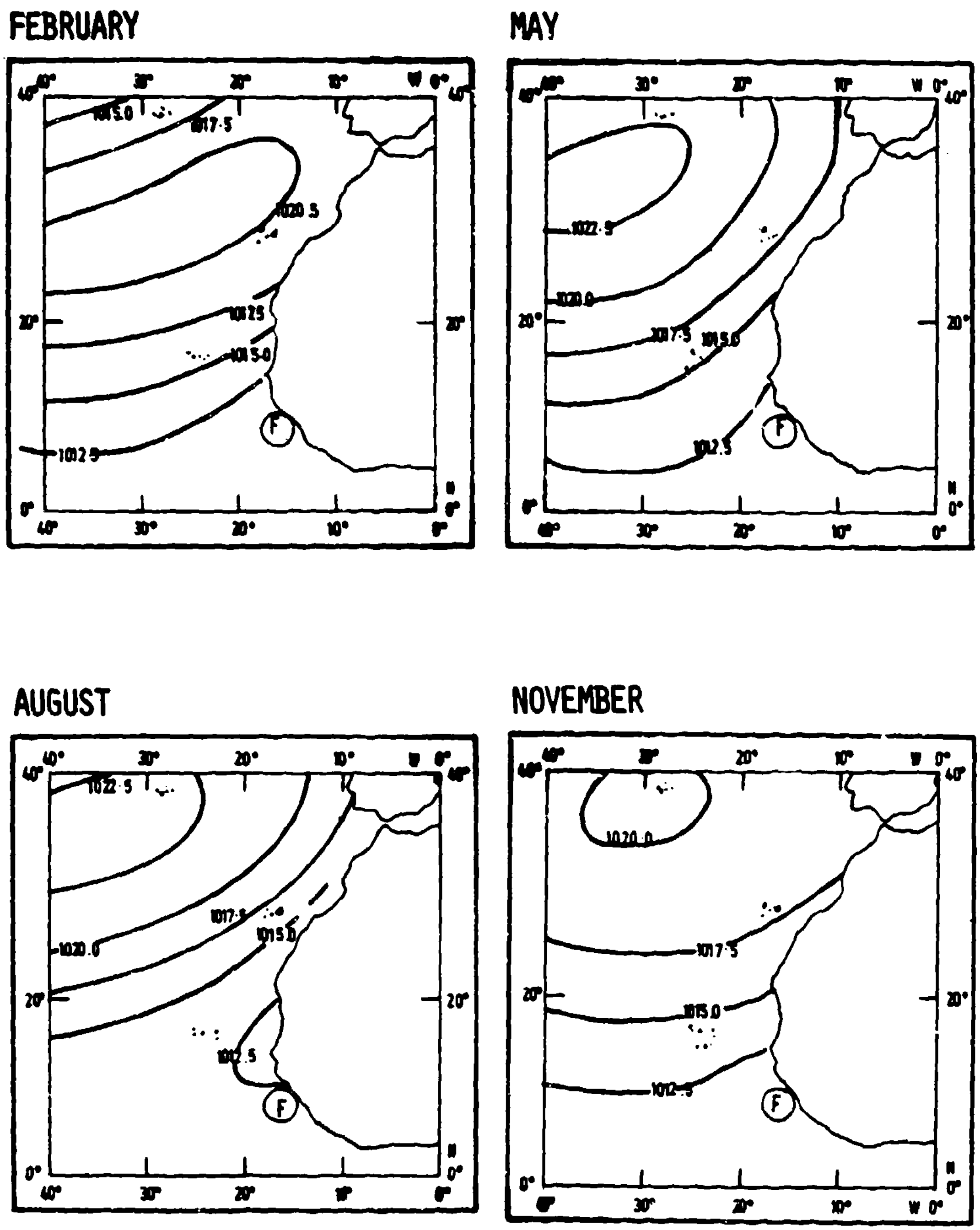


Figure F-1 - Generalized Ocean Currents for the Atlantic Ocean near the African Coast



——— Mean Sea Level Pressure in Millibars

Figure F-2 - Seasonal Mean Sea Level Pressures

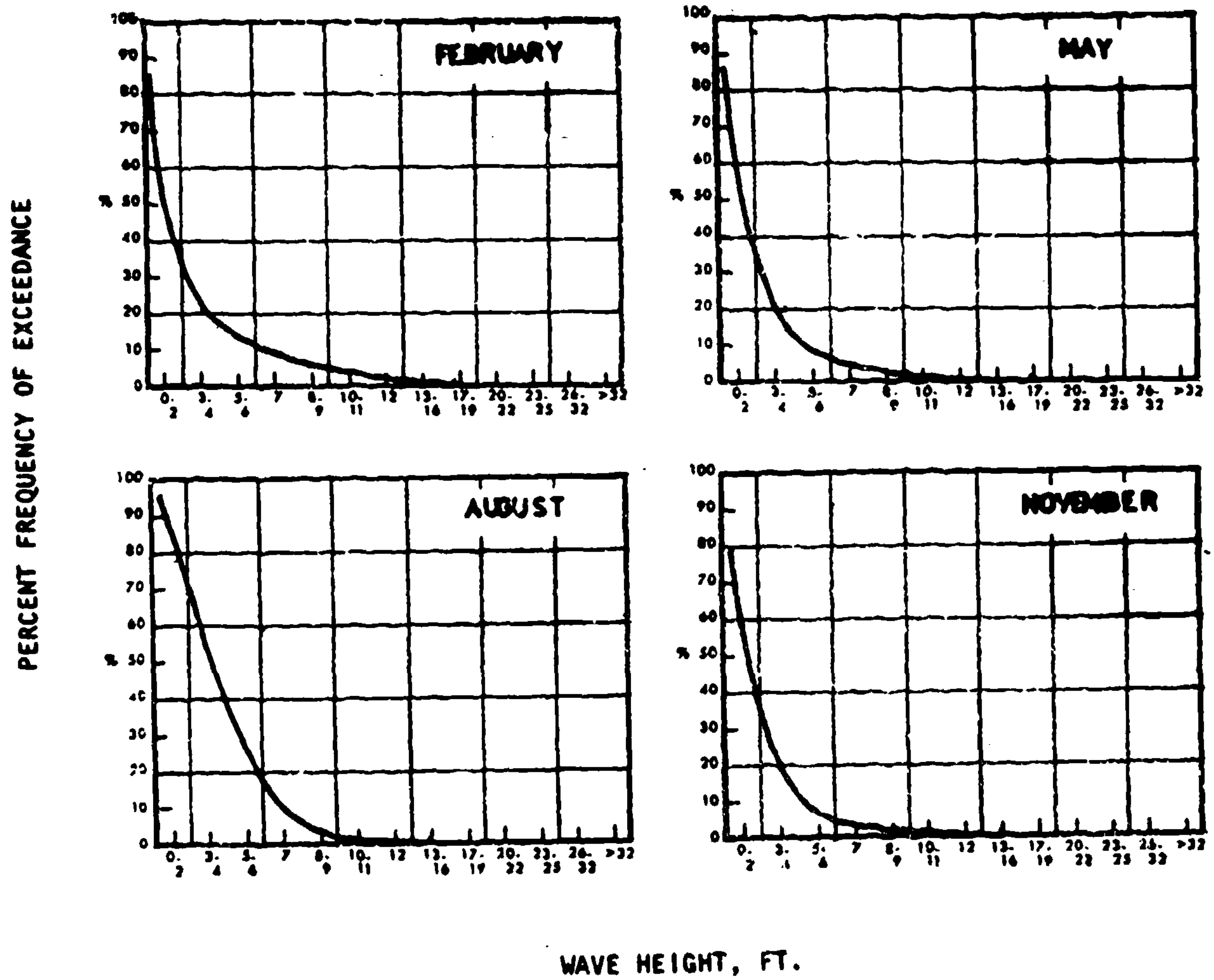
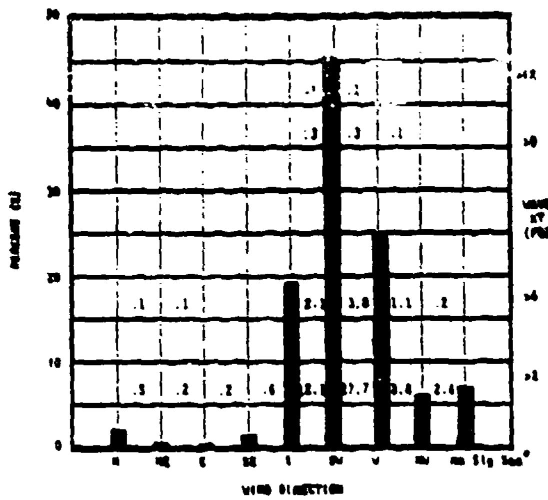


Figure F-3 - Seasonal Wave Height Exceedances

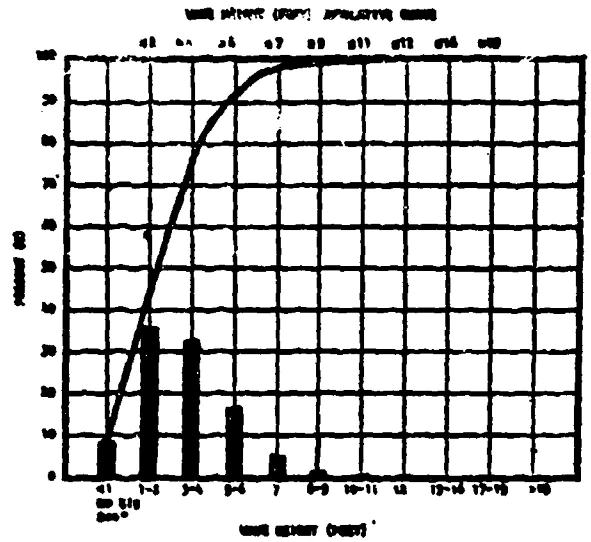
PART II. SUMMER (AUGUST) CLIMATOLOGY OF THE SOUTHEASTERN NORTH ATLANTIC: 9°30' N, 16°0' W (OFF GUINEA)

The following data graphs are derived primarily from Volume 2 of the West African and Selected Island Coastal Marine Areas (Area 9) of Reference 5 for the worst wind/wave season, August. Figure F-4a is adopted from Reference 18. Figure F-11b is adopted from Reference 3.



*No Significant Sea. Either wave conditions were calm or the only wave observed was small waves.

Figure F-1a - Sea Height by Wind Direction



*No Significant Sea. Either wave conditions were calm or the only wave observed was small waves.

Figure F-1b - Sea Height - Cumulative Distribution

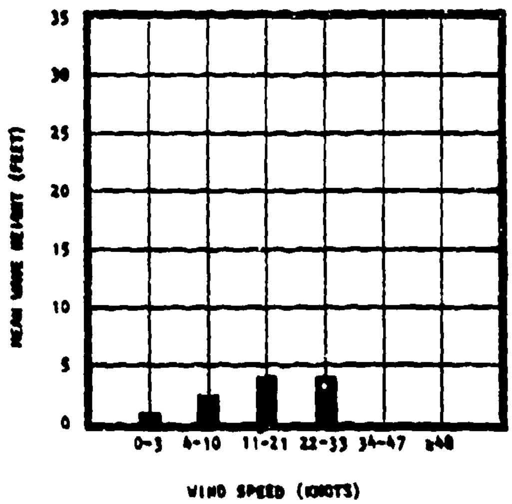


Figure F-1c - Mean Sea Height by Wind Speed

NOT AVAILABLE

Figure F-1d - Swell Height by Direction

NOT AVAILABLE

Figure F-1e - Swell Height - Cumulative Distribution

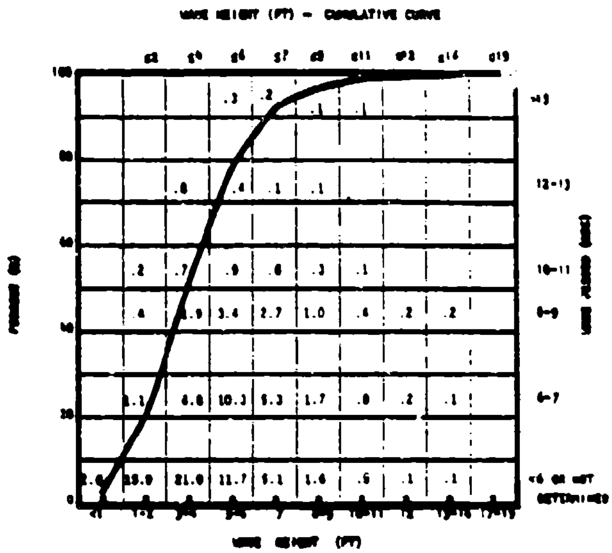


Figure F-1f - Wave Height and Period

NOT AVAILABLE

Figure F-1g - Return Periods for High Waves

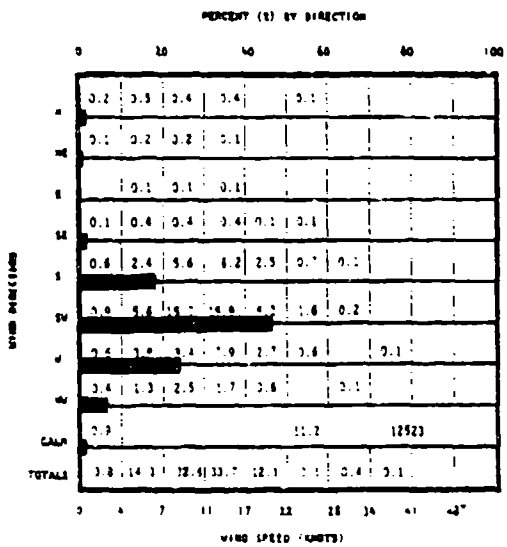


Figure F-2a - Wind Speed by Direction

NOT AVAILABLE

Figure F-2b - Return Periods for Maximum Sustained Winds

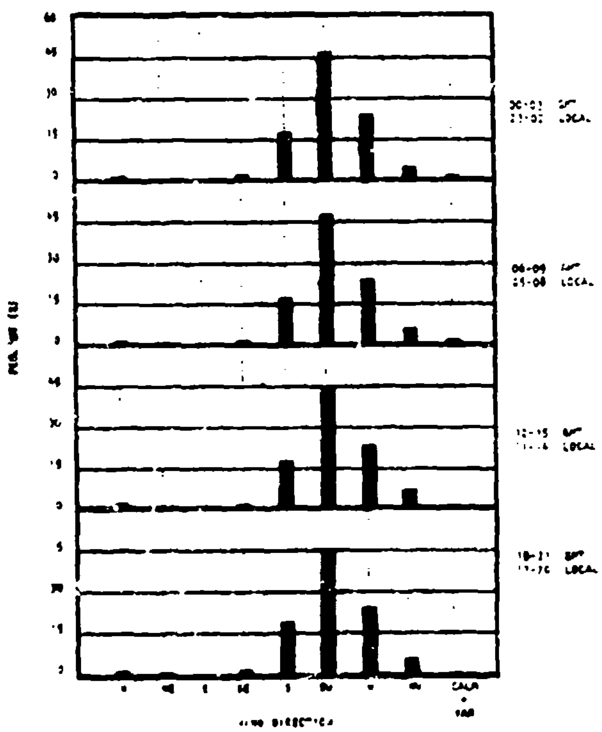


Figure F-2c - Wind Direction - Diurnal Variations

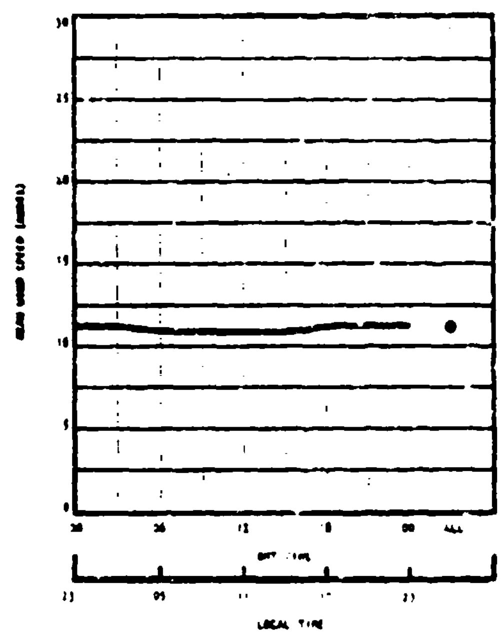


Figure F-2d - Wind Speed - Diurnal Variation

NOT AVAILABLE

Figure F-2e - Gale Persistence

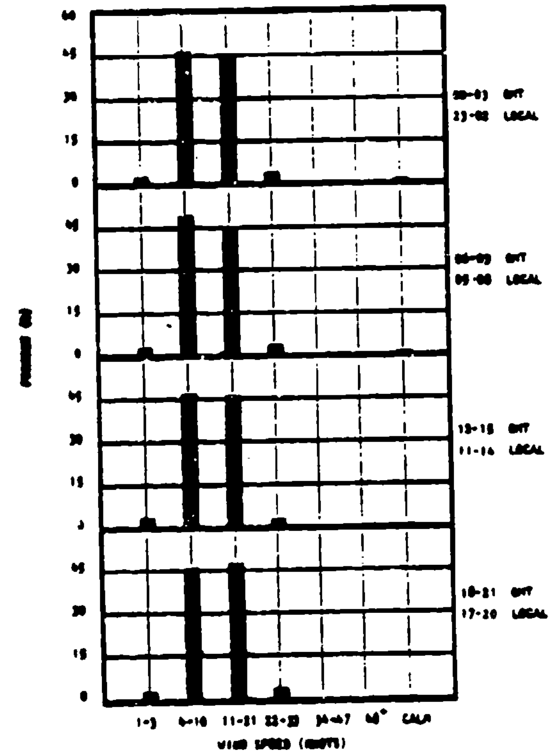


Figure F-2f - Wind Speed - Diurnal Variation

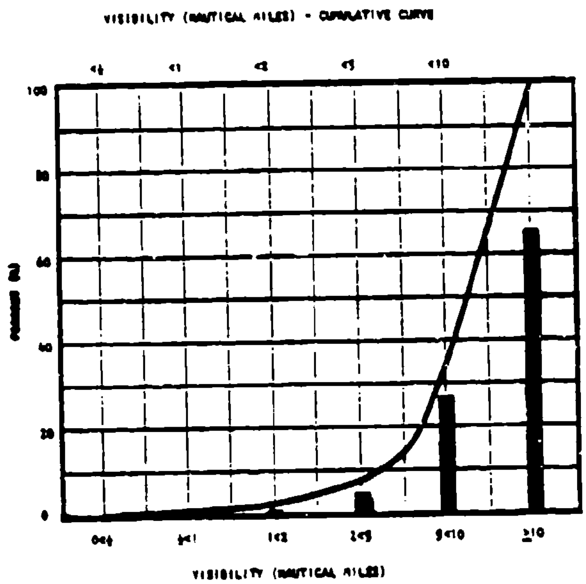


Figure F-3a - Visibility - Cumulative Distribution

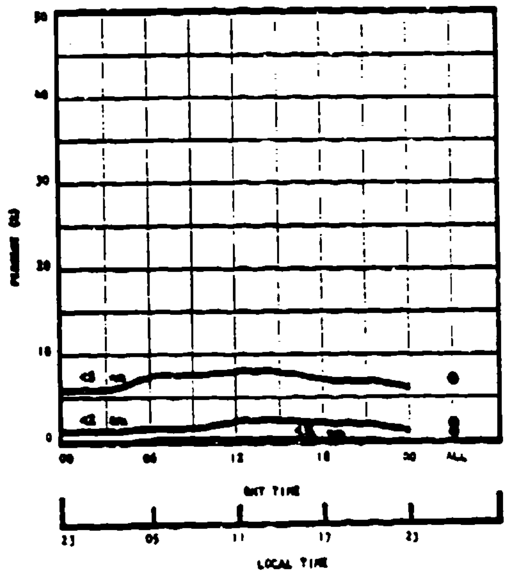


Figure F-3b - Visibility - Diurnal Variation

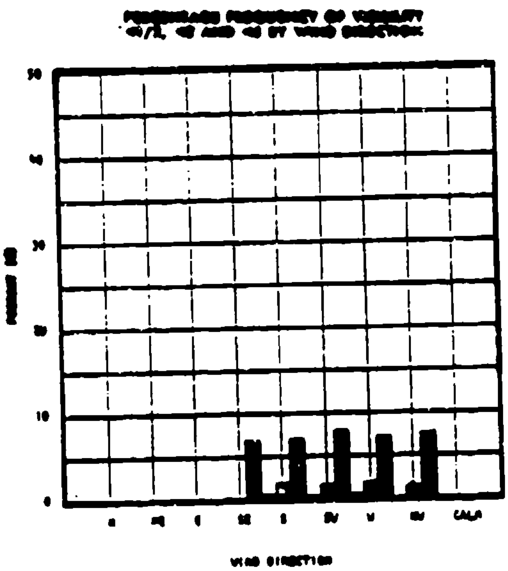


Figure F-3c - Visibility by Wind Direction

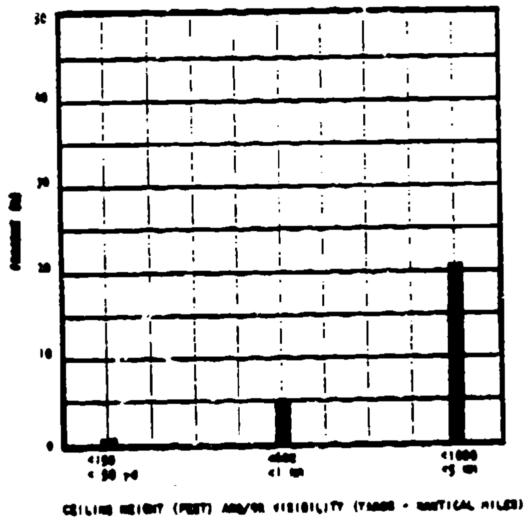


Figure F-3d - Low Visibility and/or Ceiling Height

NOT AVAILABLE

Figure F-3e - Visibility Persistence

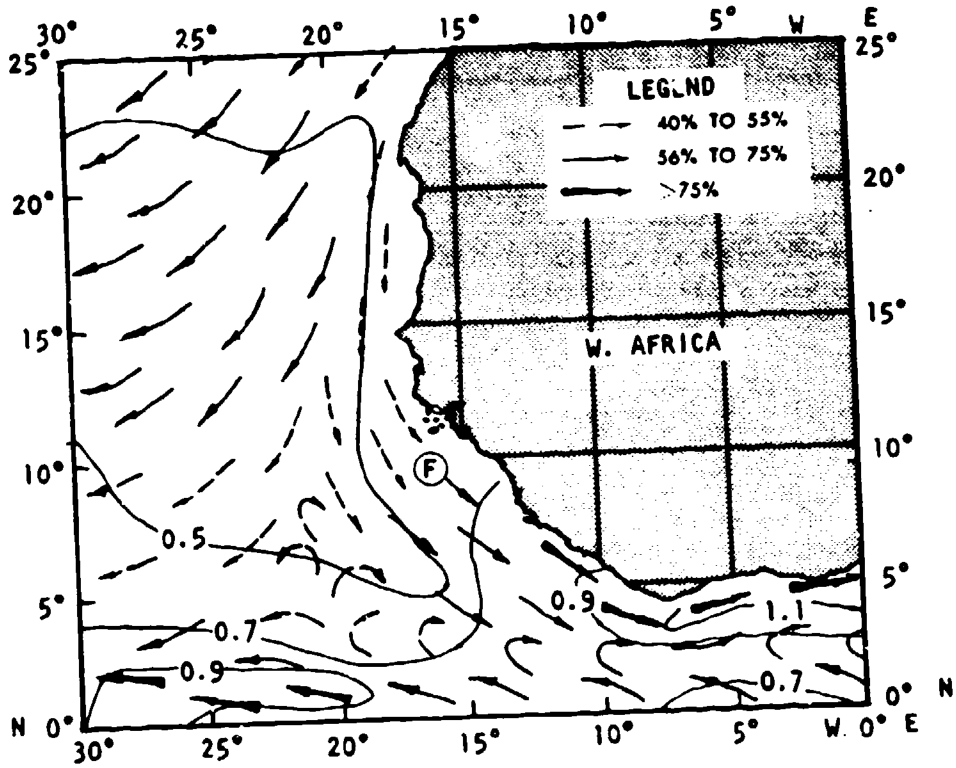


Figure F-4a - Mean Surface Current Speeds and Prevailing Directions

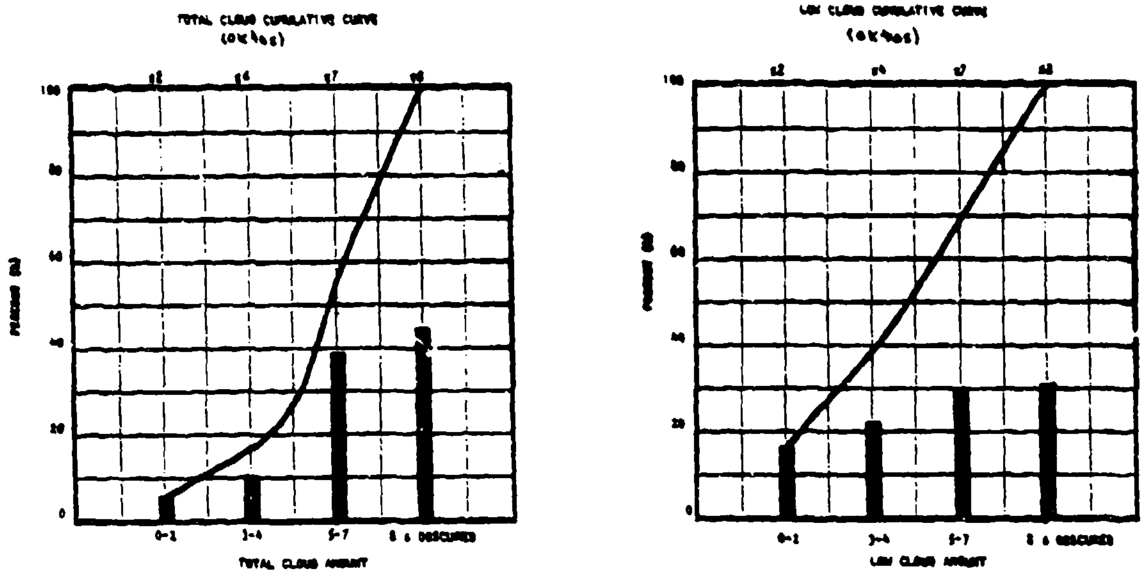


Figure F-5a - Cloud Amounts - Cumulative Distribution

NOT AVAILABLE

Figure F-5b - Mean Cloud Amounts

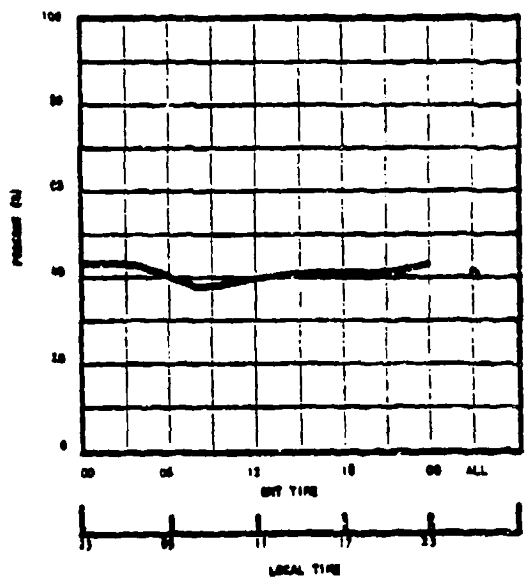


Figure F-5c - Good Cloud Conditions - Diurnal Variation

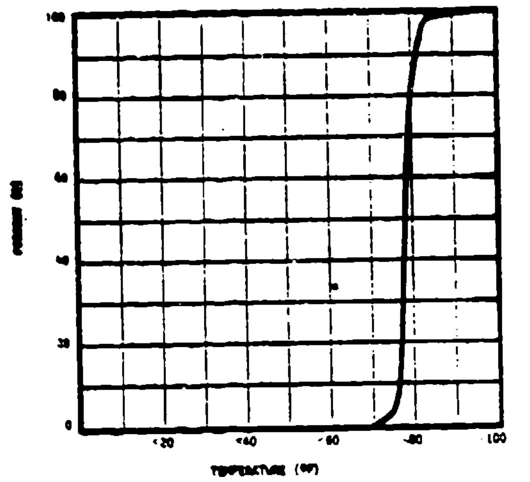


Figure F-6a - Air Temperature - Cumulative Distribution

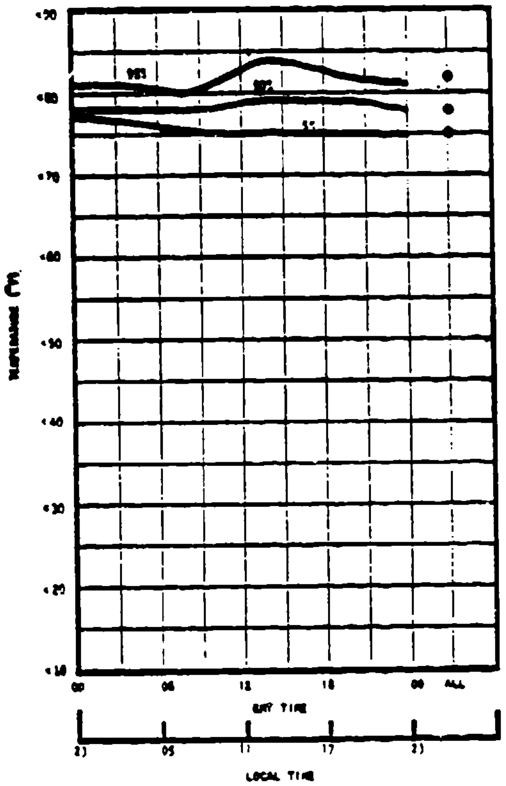


Figure F-6b - Air Temperature - Diurnal Variation

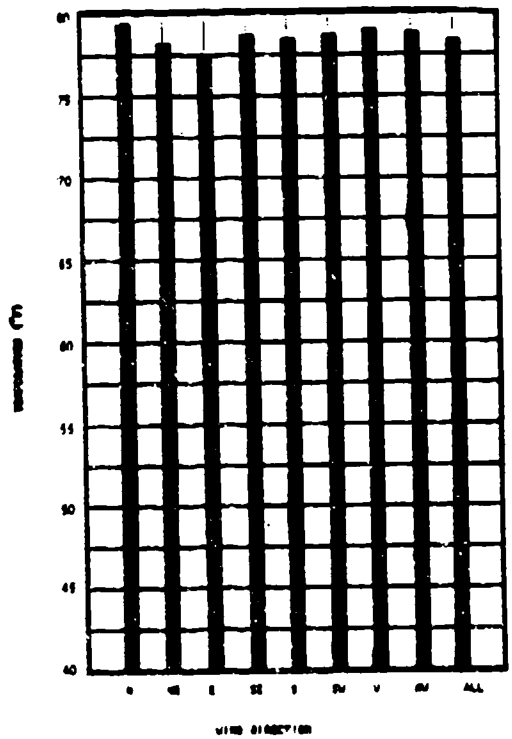


Figure F-6c - Mean Air Temperature by Wind Direction

NO OCCURENCES
(SUB-FREEZING TEMP.)
REPORTED

Figure F-6d - Air Temperature and Gales

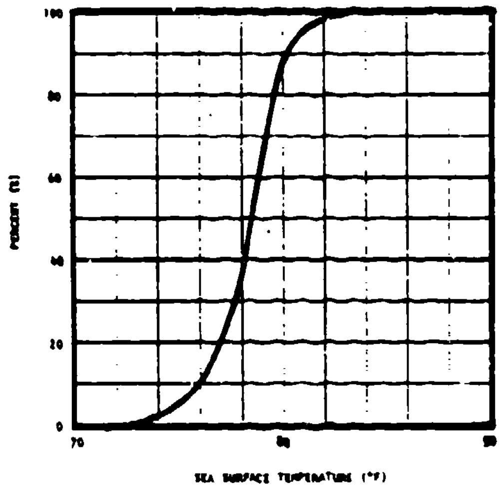


Figure F-6e - Sea Surface Temperature

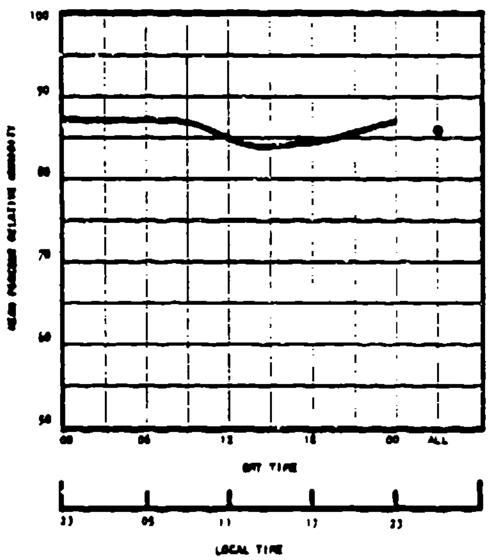


Figure F-6f - Relative Humidity - Diurnal Variation

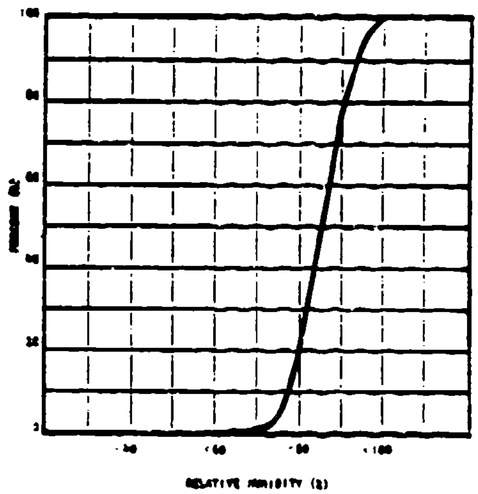


Figure F-6g - Relative Humidity - Cumulative Distribution

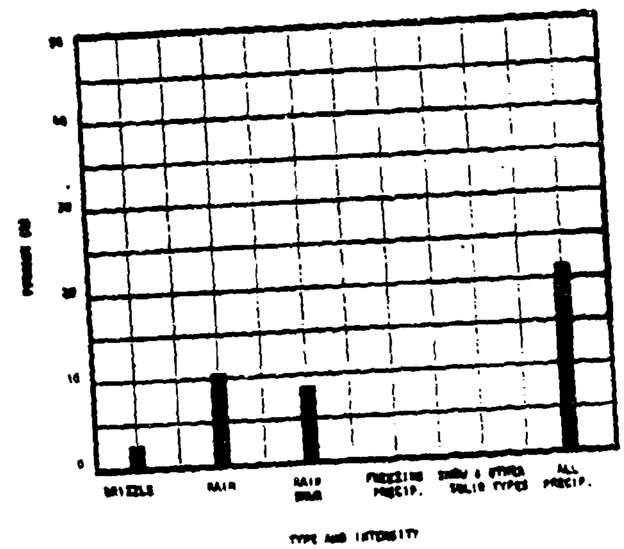


Figure F-7a - Precipitation by Type

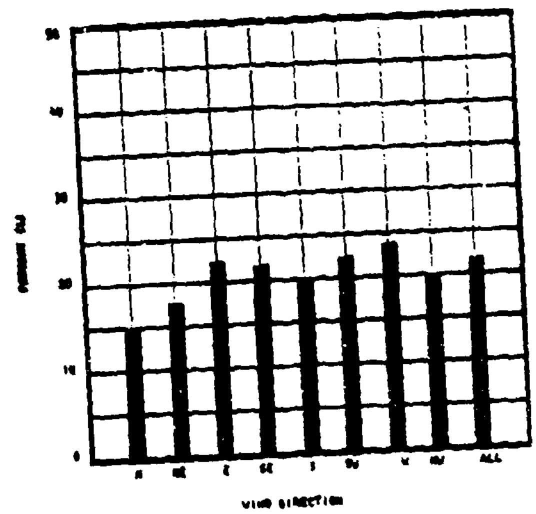


Figure F-7b - Precipitation by Wind Direction

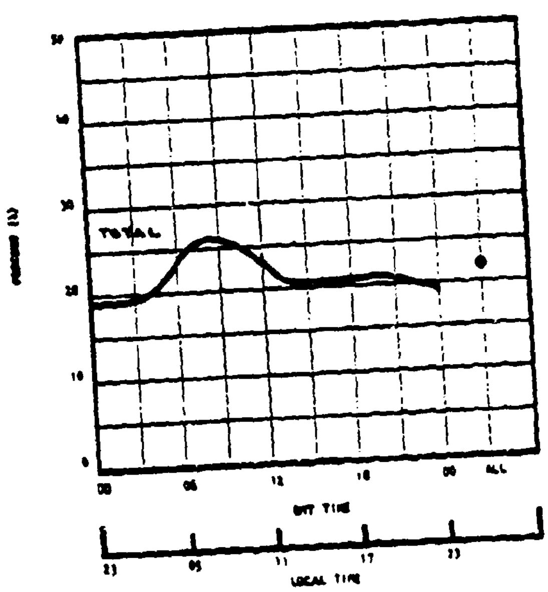


Figure F-7c - Precipitation - Diurnal Variation

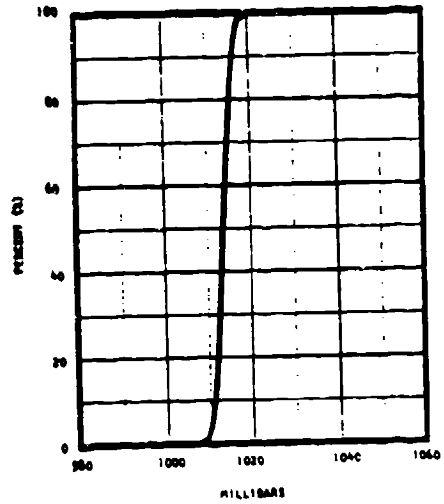


Figure F-8a - Sea Level Pressure - Cumulative Distribution

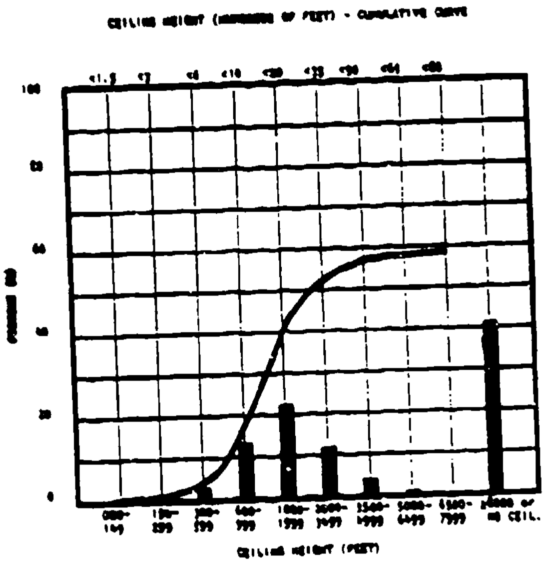


Figure F-9a - Ceiling Height

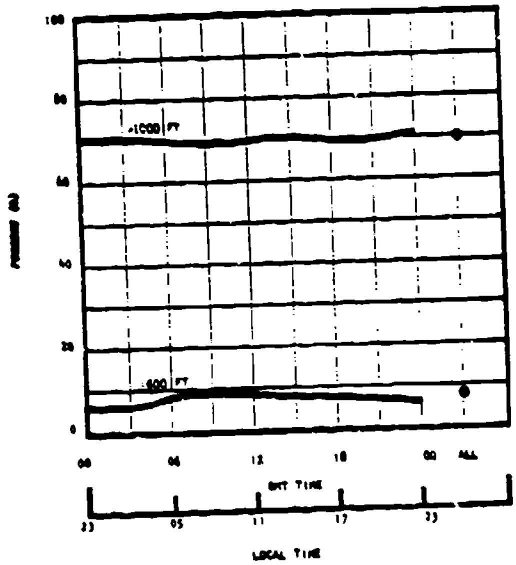


Figure F-9b - Ceiling Height - Diurnal Variation

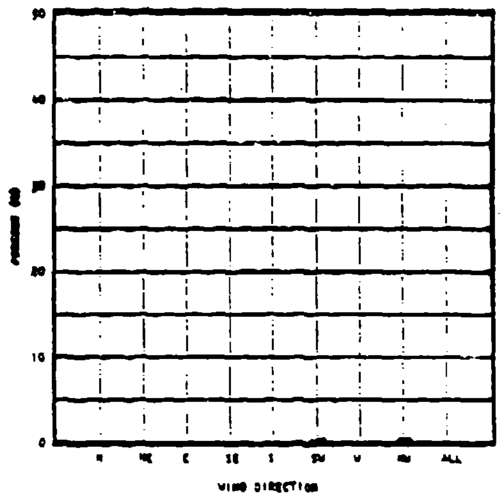


Figure F-10a - Fog versus
Wind Direction

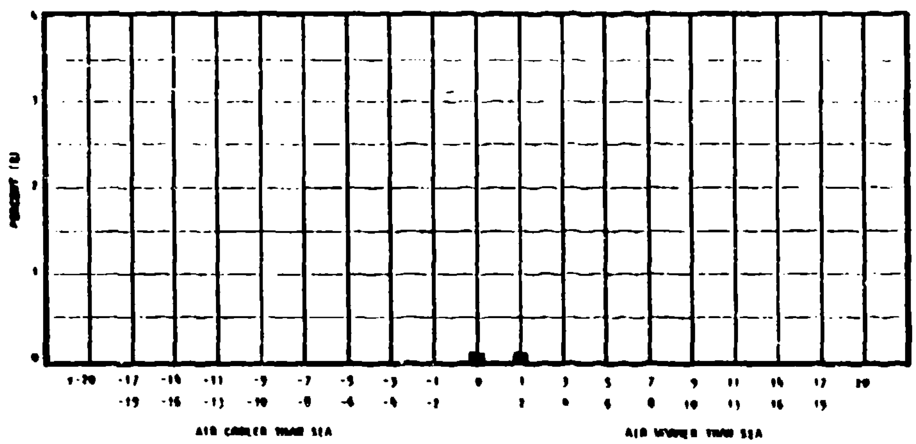


Figure F-10b - Fog versus
Air - Sea Temperature Difference

NO OCCURRENCES REPORTED

Figure F-11a - Low Pressure Centers

(SEE NEXT PAGE)

Figure F-11b - Tropical Cyclones

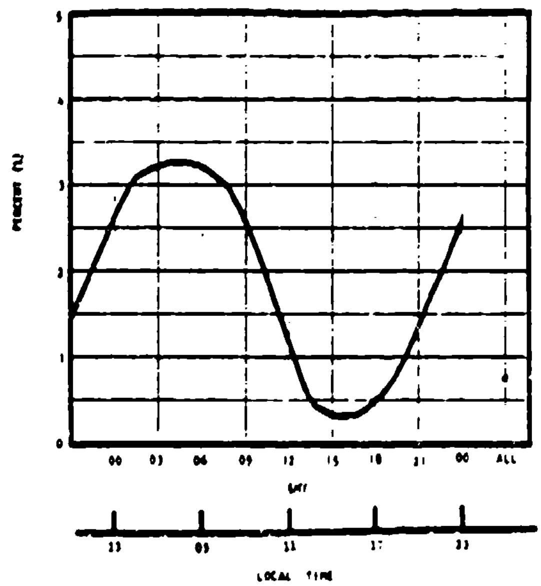


Figure F-11c - Thunderstorms

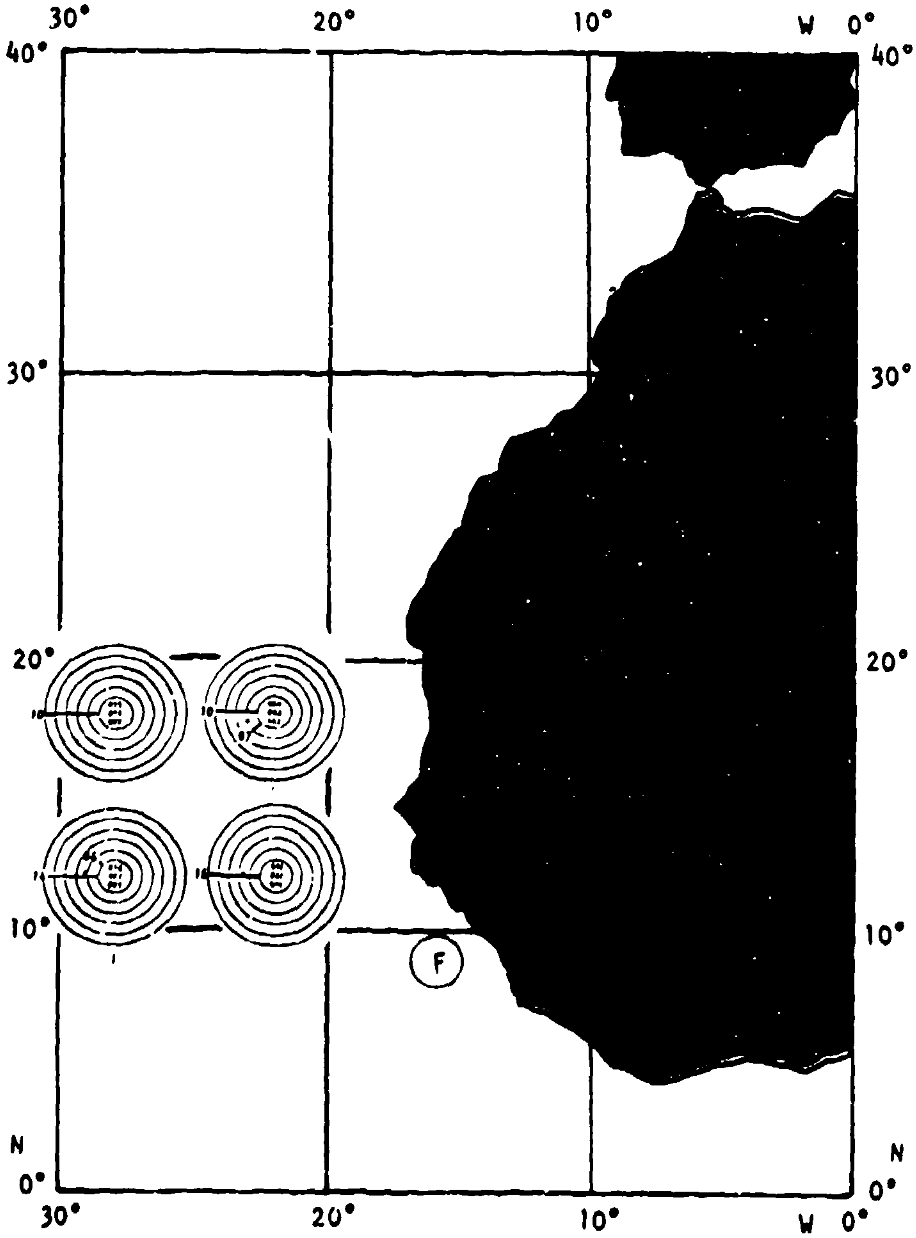


Figure F-11b - Tropical Cyclones

NO OCCURRENCES REPORTED

Figure F-12a - Concentration

Figure F-12b - Icebergs

Figure F-13a - Percentage frequency of moderate and severe potential for superstructure icing

APPENDIX G

MARINE CLIMATOLOGY OF THE NORTH PACIFIC:

50°N, 180°W (OFF THE ALEUTIANS)

PART I. GENERAL MARINE CLIMATOLOGY OF THE NORTH PACIFIC: 50°N, 180°W (OFF THE ALEUTIANS)

1. A general climatology for the oceanographic area defined by 50°N, 180°W is developed. The area is denoted as Location G on Figure G-1 and is considered important to U.S. Navy operations because of its proximity to the Soviet Union and as a gateway to the Orient. The primary data sources are References 5, 6, 19, and 20.

2. Location G is situated near (south of) the Aleutian Islands which extend over a distance of 900 miles and are located south of the Alaska peninsula and the Bering Sea. This location places the island chain inside a major typhoon route which brings severe storms to the area. Thick weather is prevalent and the currents and tidal streams in the vicinity are strong, making navigation difficult. The temperatures in the area vary because of the Alaska currents and typhoons. There is not a strong spring or fall, and the summer season is a short one with hazardous climatic conditions such as fog and fresh winds. The islands and surrounding waters have been relatively unexplored and may contain many unknown dangers. Thus, there is a lack of recorded information for this region, especially over the open sea where what records exist are incomplete and thus potentially misleading.

3. A coastal current, known as the Alaska current, which is an offshoot of the generally eastward drift of warm current across the middle latitude of the North Pacific, flows westward along the islands on the south shore and eastward on the north shore, see Figure G-1. The direction of the current is influenced by the direction of the wind and the current speed is generally less than 1 knot. Between some islands there are intermixing currents which generally move in a northward direction. At Location G, the current is from the north to northeast and in general varies little throughout the year.

4. The Aleutian Low is the dominating pressure system influencing weather near the Aleutian Islands. It is separated from the Icelandic Low which dominates the weather over the northern Atlantic by the high pressure system over North America. The Aleutian Low is weakest in summer when there is merely a low pressure trough extending over northeastern Siberia. Figure

G-2 indicates the mean seasonal sea level pressures and storm tracks for the area surrounding Location G. Values range from about 1000 millibars in winter (February) to 1012.5 millibars in summer (August).

5. The area around the Aleutian Islands is one of the stormiest regions in the Northern Hemisphere. Gales at sea are frequent from fall to spring. Violent squalls from the coastal mountains occur regularly. Wind directions are variable, though winds from the southwest, west, and northwest are slightly more common. Gale force winds of 34 knots or more occur 14 percent or more of the time in winter, 4 percent or more in spring, 1 percent or more in summer, and 13 percent or more in fall.

Mean wind speed drops in spring and summer to between 14 and 16 knots from the mean winter and fall speed of 21 knots.

6. The wave heights accompanying the fall and winter gale force winds have been observed to be as great as 25 feet. Generally the sea direction is similar to the wind direction though some swells as large as 20 feet or more may be expected from the east and southeast in winter and fall. In general, due to the great possible fetch at Location G, swell could be expected from any remote intense Northern Pacific storms. In winter, nearly 30 percent of all observed waves exceed 12 feet and generally have periods of 8 to 13 seconds. In spring, less than 10 percent of observed waves exceed 12 feet and periods appear to be variable. In summer, probably less than 5 percent of all waves exceed 12 feet and periods are variable. In fall, nearly 30 percent of all observed waves exceed 12 feet but have a somewhat wider period range than in winter which may indicate less persistent winds. Figure G-3 summarizes the seasonal wave height occurrences at Location G.

7. In winter, the precipitation occurrence is very high with about 30 percent of all observations reporting precipitation and about 70 percent of these reporting snow. In spring, more than 15 percent of observations reported precipitation and about 10 percent of these noted snow. No snow was reported in summer but 15 percent of observations reported precipitation. In fall nearly 25 percent of observations reported precipitation, 30 percent of which were snow.

8. This is one of the foggiest regions in the world. Sea fogs are transported southward by winds though they may persist even when the northward

wind is strong. Conditions generally improve when the wind shifts eastward or southeastward. The main foggy seasons are spring and summer, with the worst conditions occurring between June and August when fog envelopes the islands nine days out of ten.

9. Although the climate to the north in the Bering Sea is rather extreme, winter becomes progressively milder and summer progressively cooler westward along the Aleutian Islands. The mean maximum temperature at Location G ranges from 37°F in winter to 57°F in summer and the mean minimum, 29°F in winter and 46°F in summer. Humidity is generally high, ranging from mean values of 56 percent in winter to 40 percent in spring.

10. The sea surface temperature is higher than the air temperature most of the year except in spring and summer when the reverse is true. The mean sea temperatures are about 37°F in winter, 41°F in spring, 53°F in summer and 43°F in fall. The coldest water temperatures are registered in spring when the ice begins to melt, sending very cold water and ice southward. A person in ordinary clothes and life preserver may be expected to survive in the waters about Location G only about 30 to 90 minutes in winter and spring, 1 to 6 hours in summer, and 1 to 3 hours in fall. Exhaustion or unconsciousness will set in probably in half that time. Generally ice is not expected in the area about Location G in winter though moderate* superstructure icing in winter should be expected for more than 6 percent of the time. In fall, moderate superstructure icing is a very rare occurrence. In spring small pieces of floating ice might pass through the islands, from the Bering Sea, towards Location G.

11. Visibility is poor during foggy days and is nearly always low at dawn. Fog originates in the North Pacific between 40 and 50°N and is carried towards Location G and the Aleutians by southerly winds. Wind shifts to the west or north may improve the visibility loss due to this persistent fog in spring and summer.

In winter, visibility is less than 2 nautical miles in over 10 percent of observations and 5 nautical miles or greater in over 70 percent of

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*Moderate here means a buildup of less than one-tenth of an inch per hour and is derived from observations with temperature less than or equal to 28°F and wind speed greater than or equal to 13 knots.

observations. In contrast, in summer, visibility is less than 2 nautical miles in about 30 percent of observations and 5 nautical miles or greater in only about 50 percent of observations.

12. The maximum number of daylight hours occurs in June and is slightly more than 16 hours. The minimum number of daylight hours is about 8 hours, which occurs in late December.

13. Navigation near the Aleutians can be hazardous since the bottom of the sea is rocky and the boulders unmarked by kelp. The island chain is part of a volcanic ridge that descends into the Aleutian Trench and can produce earthquakes and tsunamis. The water depth at Location G, located in the Trench, is 3000 fathoms. In summer, the Aleutian Islands serve as a rookery for seals.

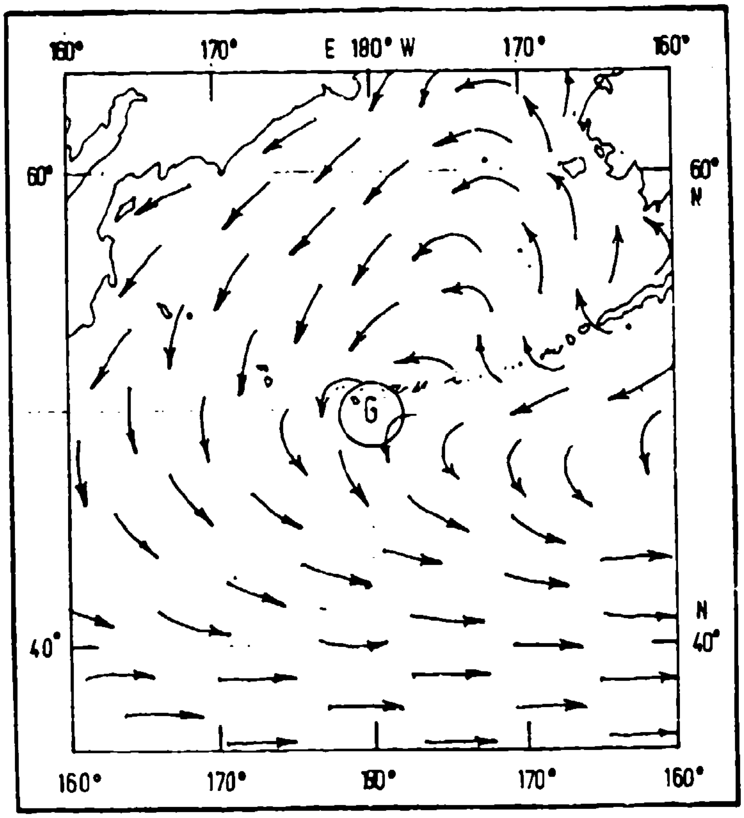
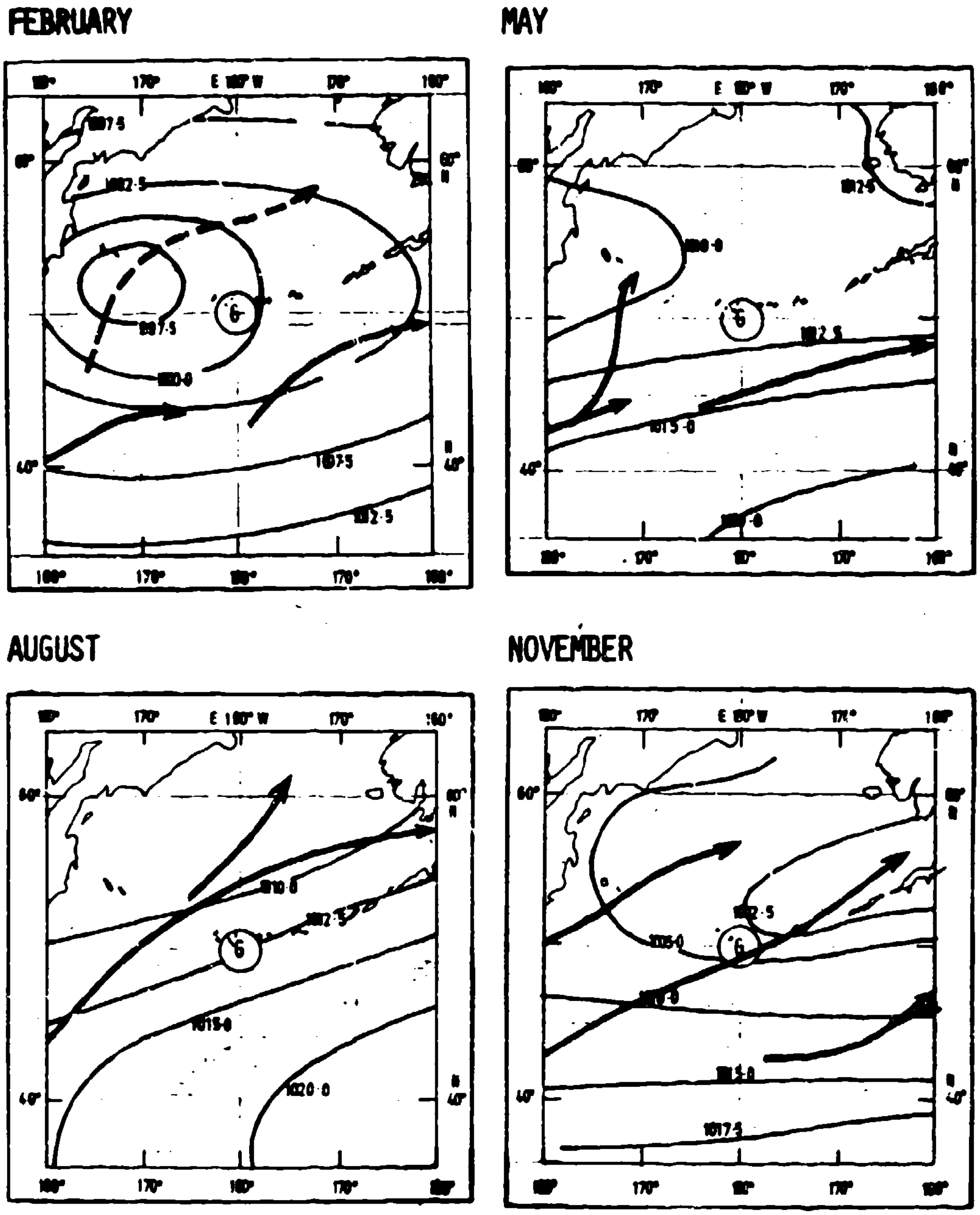


Figure G-1 - Generalized Ocean Currents for the North Pacific



——— Mean Sea Level Pressure in Millibars

———→ Primary track, along which there has been maximum concentration of individual storm center paths

- - - -→ Secondary track, along which there has been moderate concentration of individual storm center paths

Figure G-2 - Seasonal Mean Sea Level Pressures and Storm Tracks

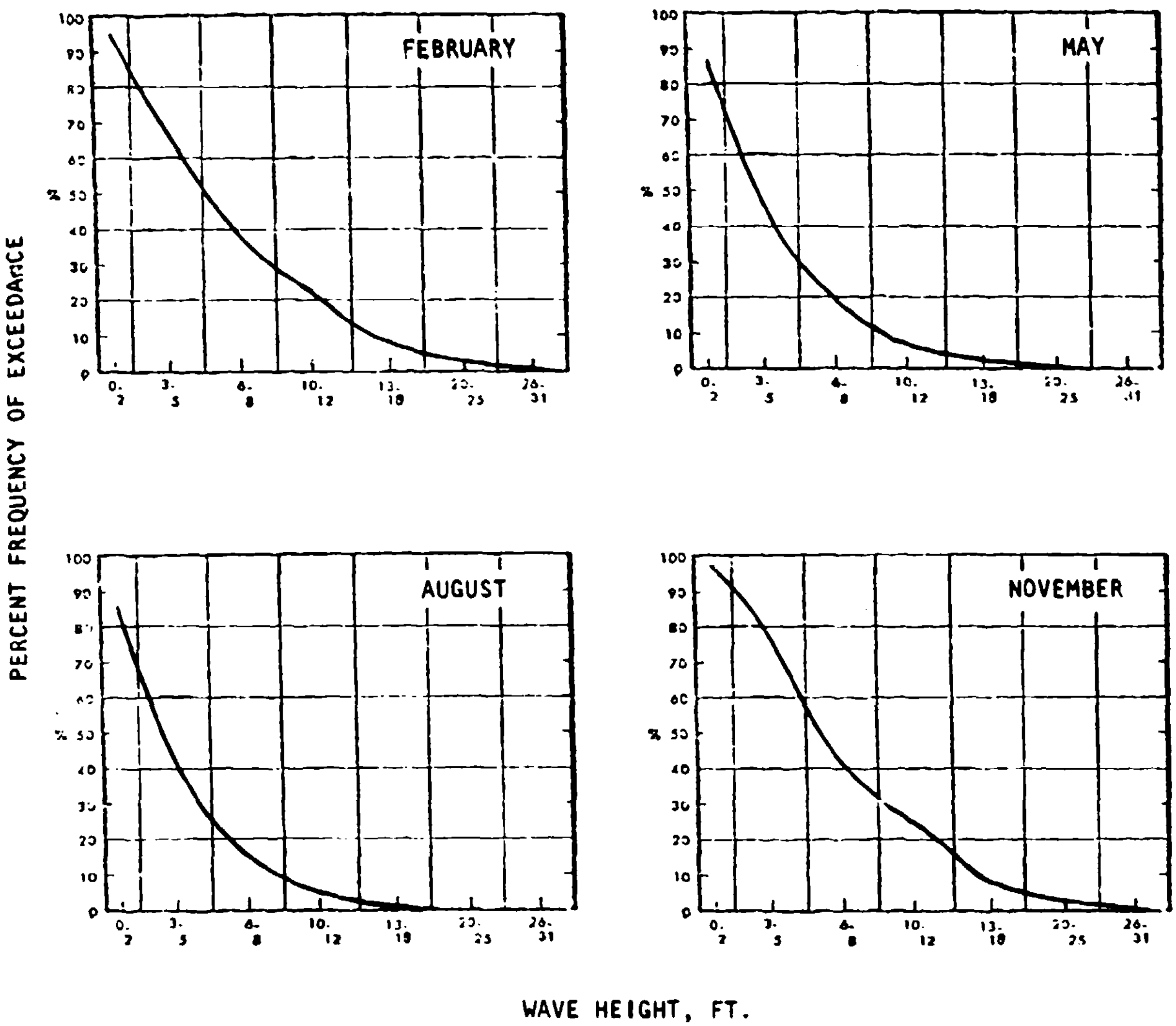


Figure G-3 - Seasonal Wave Height Exceedances

PART II. WINTER (FEBRUARY) CLIMATOLOGY OF THE NORTH PACIFIC: 50°N, 180°W (OFF THE ALEUTIANS)

The following data graphs are derived from Reference 20 (Area 12) for the worst wind/wave season, February.

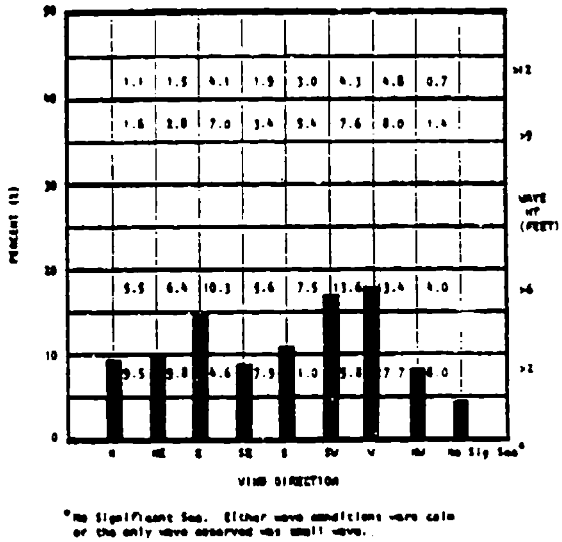


Figure G-1a - Sea Height by Wind Direction

NOT AVAILABLE

Figure G-1b - Sea Height - Cumulative Distribution

NOT AVAILABLE

Figure G-1c - Mean Sea Height by Wind Speed

NOT AVAILABLE

Figure G-1d - Swell Height by Direction

NOT AVAILABLE

Figure G-1e - Swell Height - Cumulative Distribution

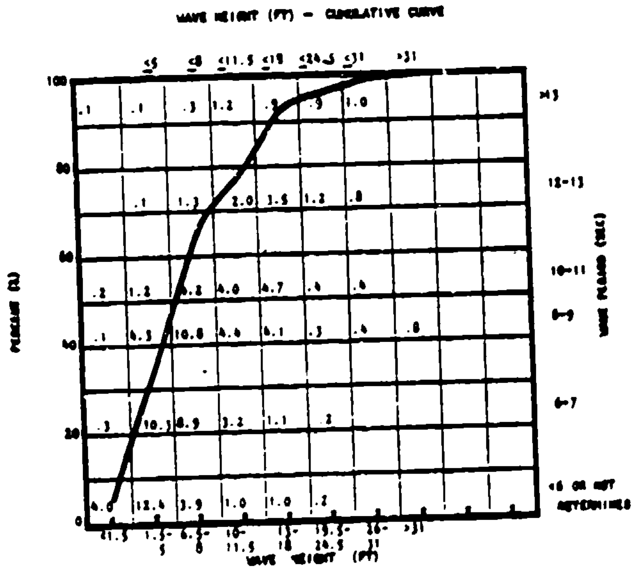


Figure G-1f - Wave Height and Period

NOT AVAILABLE

Figure G-1g - Return Periods for High Waves

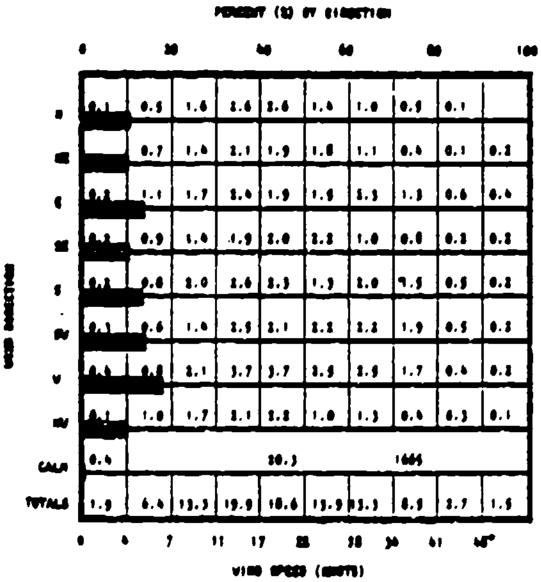


Figure G-2a - Wind Speed by Direction

NOT AVAILABLE

Figure G-2b - Return Periods for Maximum Sustained Winds

NOT AVAILABLE

Figure G-2c - Wind Direction - Diurnal Variations

NOT AVAILABLE

Figure G-2d - Wind Speed - Diurnal Variation

NOT AVAILABLE

Figure G-2e - Gale Persistence

NOT AVAILABLE

Figure G-2f - Wind Speed
Diurnal Variation

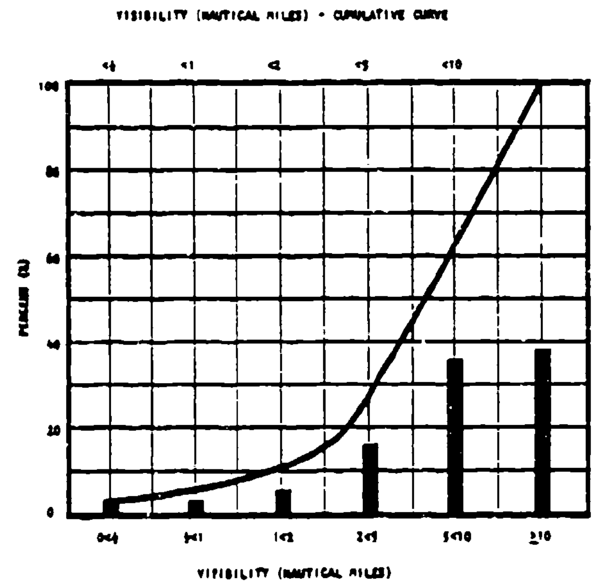


Figure G-3a - Visibility - Cumulative Distribution

NOT AVAILABLE

Figure G-3b - Visibility - Diurnal Variation

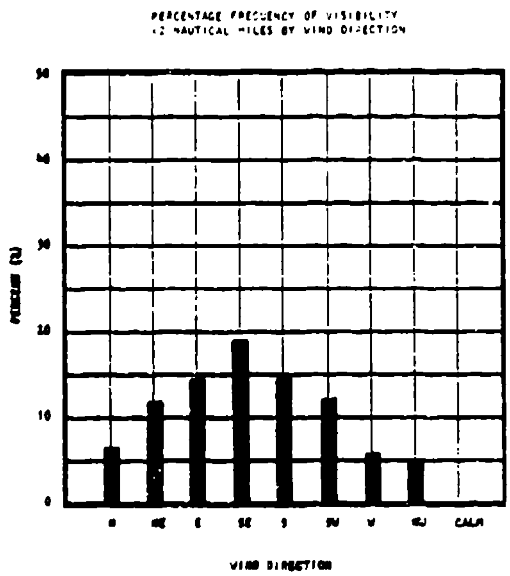


Figure G-3c - Visibility by Wind Direction

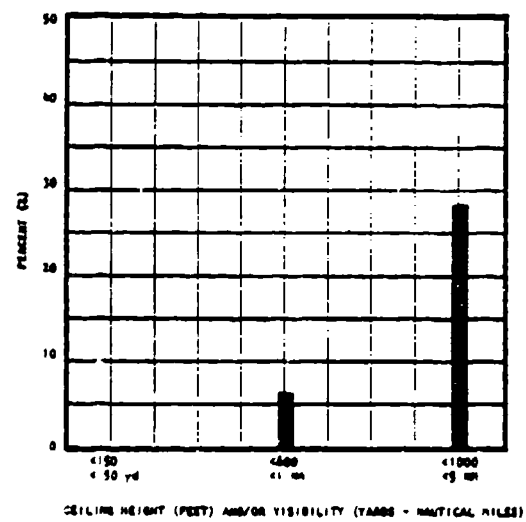


Figure G-3d - Low Visibility and/or Ceiling Height

NOT AVAILABLE

Figure G-3e - Visibility Persistence

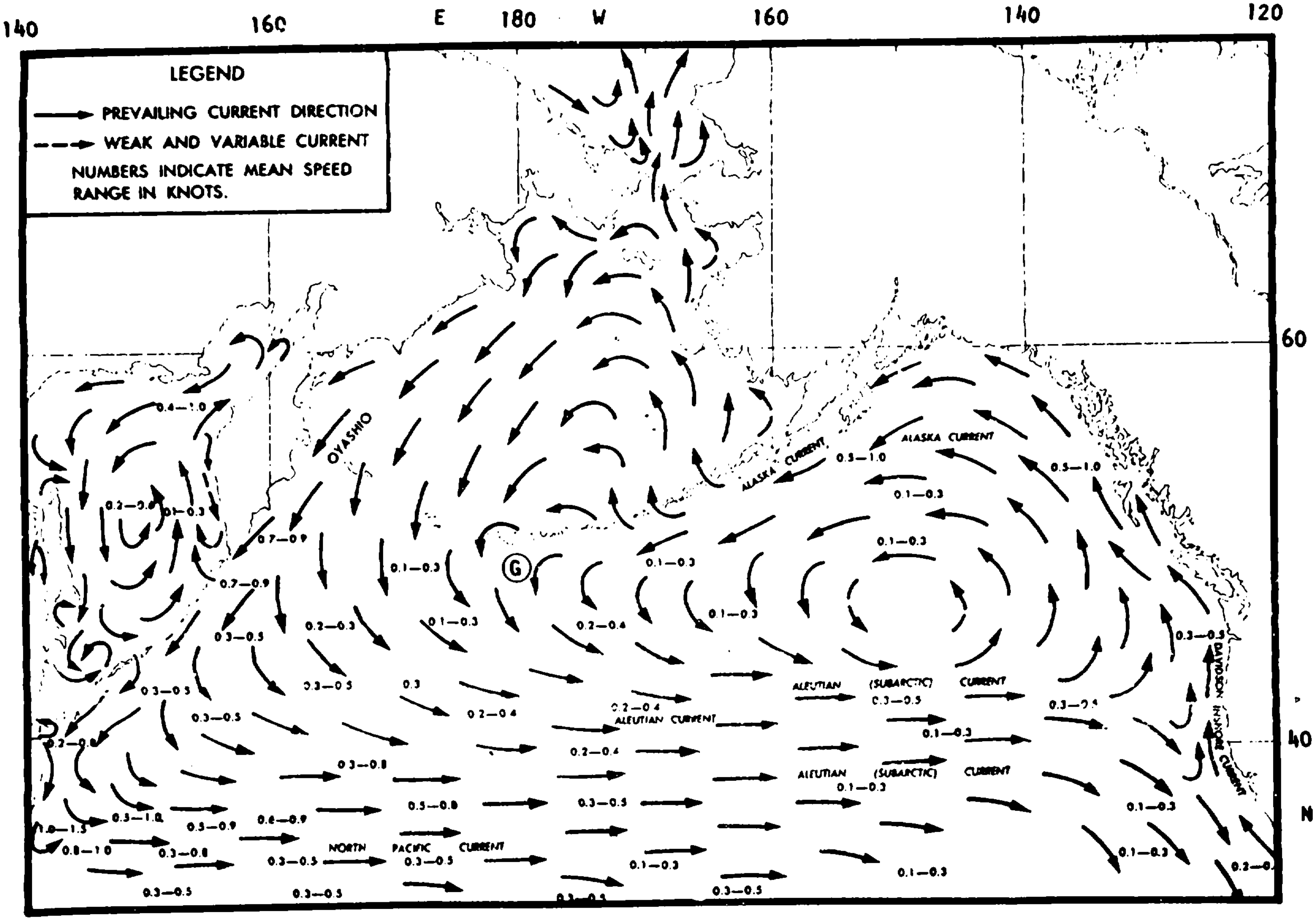
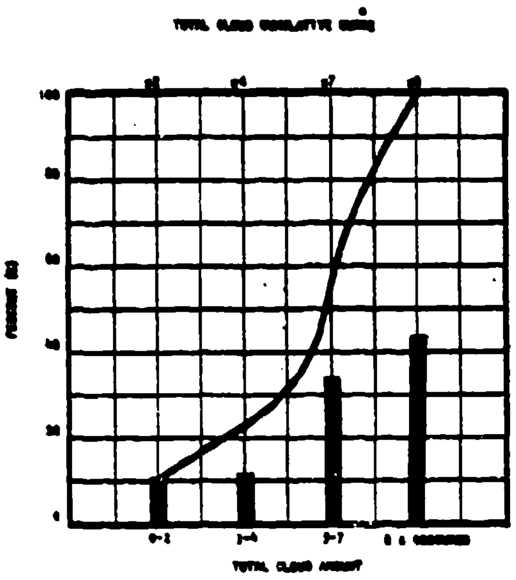


Figure G-4a - Mean Surface Current Speeds and Prevailing Directions



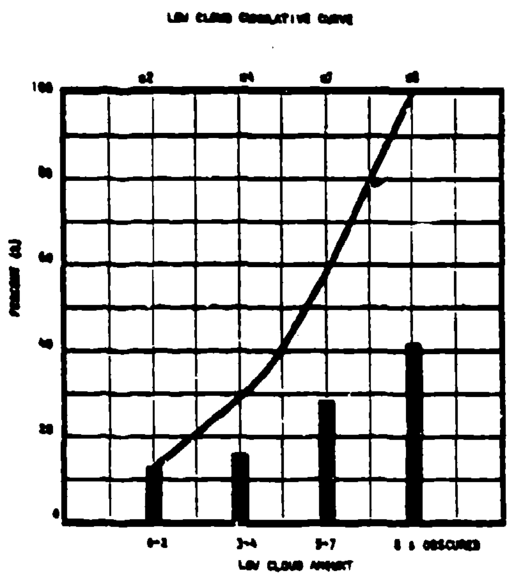


Figure G-5a - Cloud Amounts -
Cumulative Distribution

NOT AVAILABLE

Figure G-5b - Mean Cloud Amounts

NOT AVAILABLE

Figure G-5c - Good Cloud Conditions -
Diurnal Variation

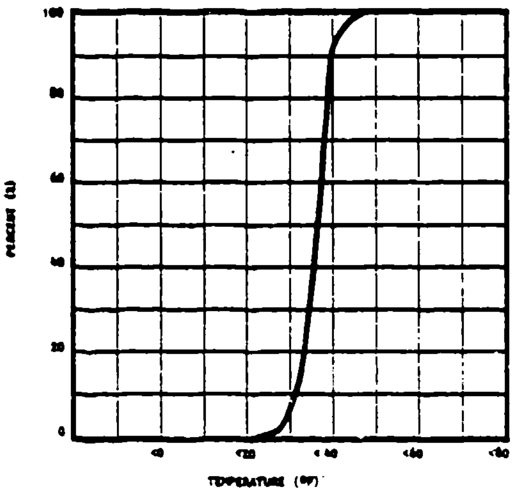


Figure G-6a - Air Temperature - Cumulative Distribution

NOT AVAILABLE

Figure G-6b - Air Temperature - Diurnal Variation

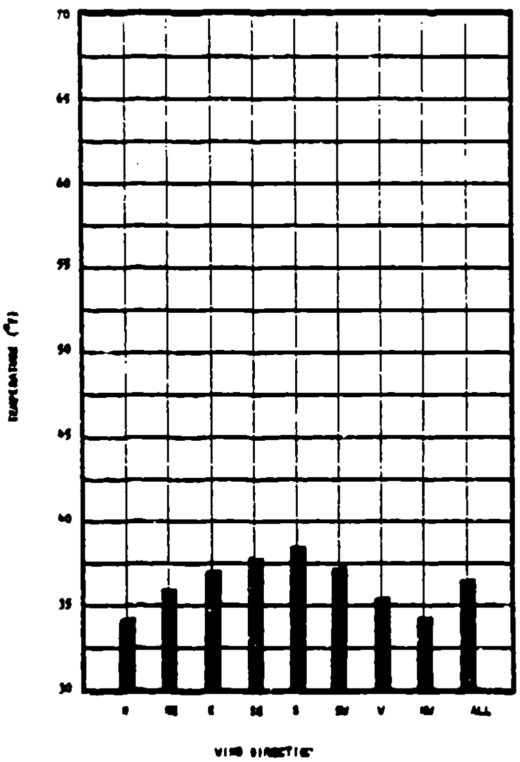


Figure G-6c - Mean Air Temperature by Wind Direction

PERCENTAGE FREQUENCY OF SUB-FREEZING TEMPERATURES

Wind Speed	Feb	May	Aug	Nov
22-33	2.5	0.5	0.0	0.5
>34	1.0	0.0	0.0	0.5

Figure G-6d - Air Temperature and Gales

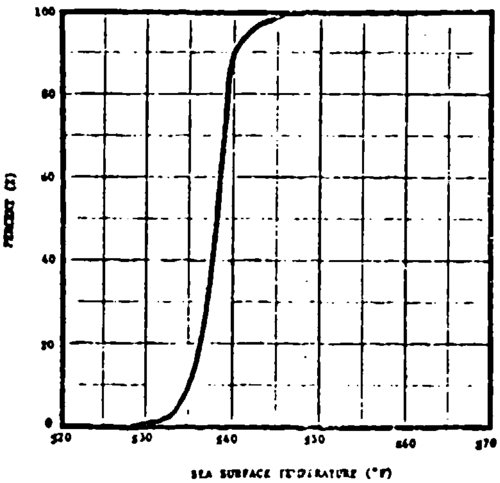


Figure G-6e - Sea Surface Temperature

NOT AVAILABLE

Figure G-6f - Relative Humidity Diurnal Variation

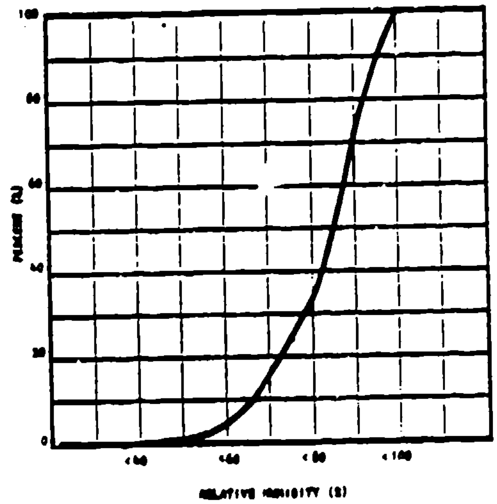


Figure G-6g - Relative Humidity - Cumulative Distribution

NOT AVAILABLE

Figure G-7a - Precipitation by Type

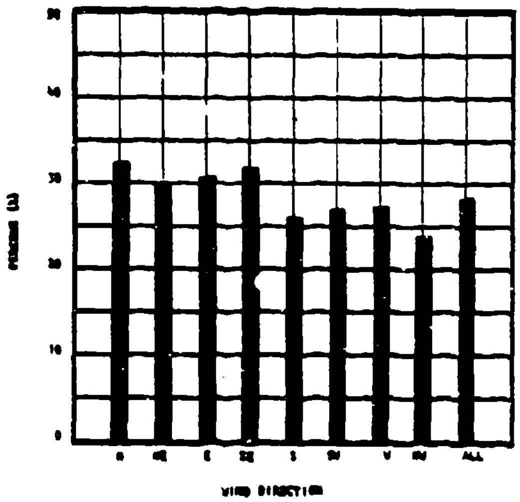


Figure G-7b - Precipitation by W' ' Direction

NOT AVAILABLE

Figure G-7c - Precipitation - Diurnal Variation

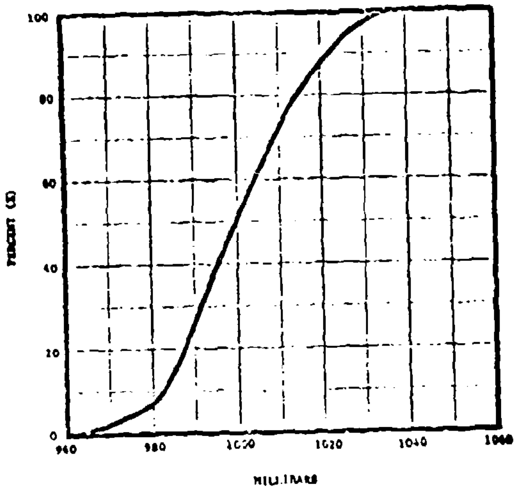


Figure G-8a - Sea Level Pressure -
Cumulative Distribution

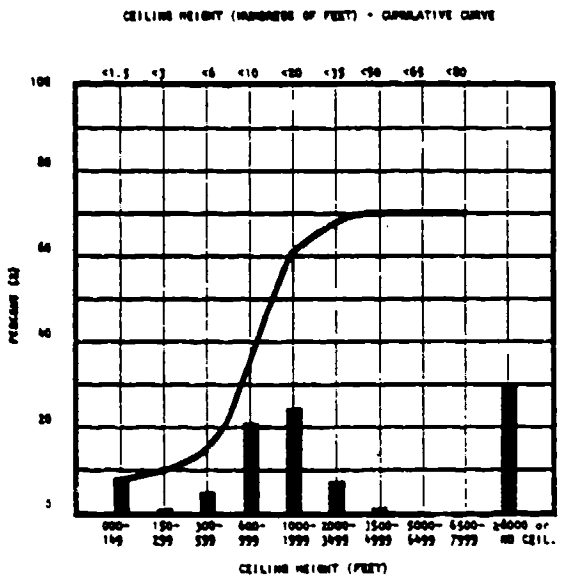


Figure G-9a - Ceiling Height

NOT AVAILABLE

Figure G-9b - Ceiling Height - Diurnal Variation

NOT AVAILABLE

Figure G-10a - Fog versus
Wind Direction

NOT AVAILABLE

Figure G-10b - Fog versus Air -
Sea Temperature Difference

(SEE NEXT PAGE)

NO OCCURRENCES REPORTED

Figure G-11a - Low Pressure Centers

Figure G-11b - Extratropical Cyclones

NOT AVAILABLE

Figure G-11c - Thunderstorms

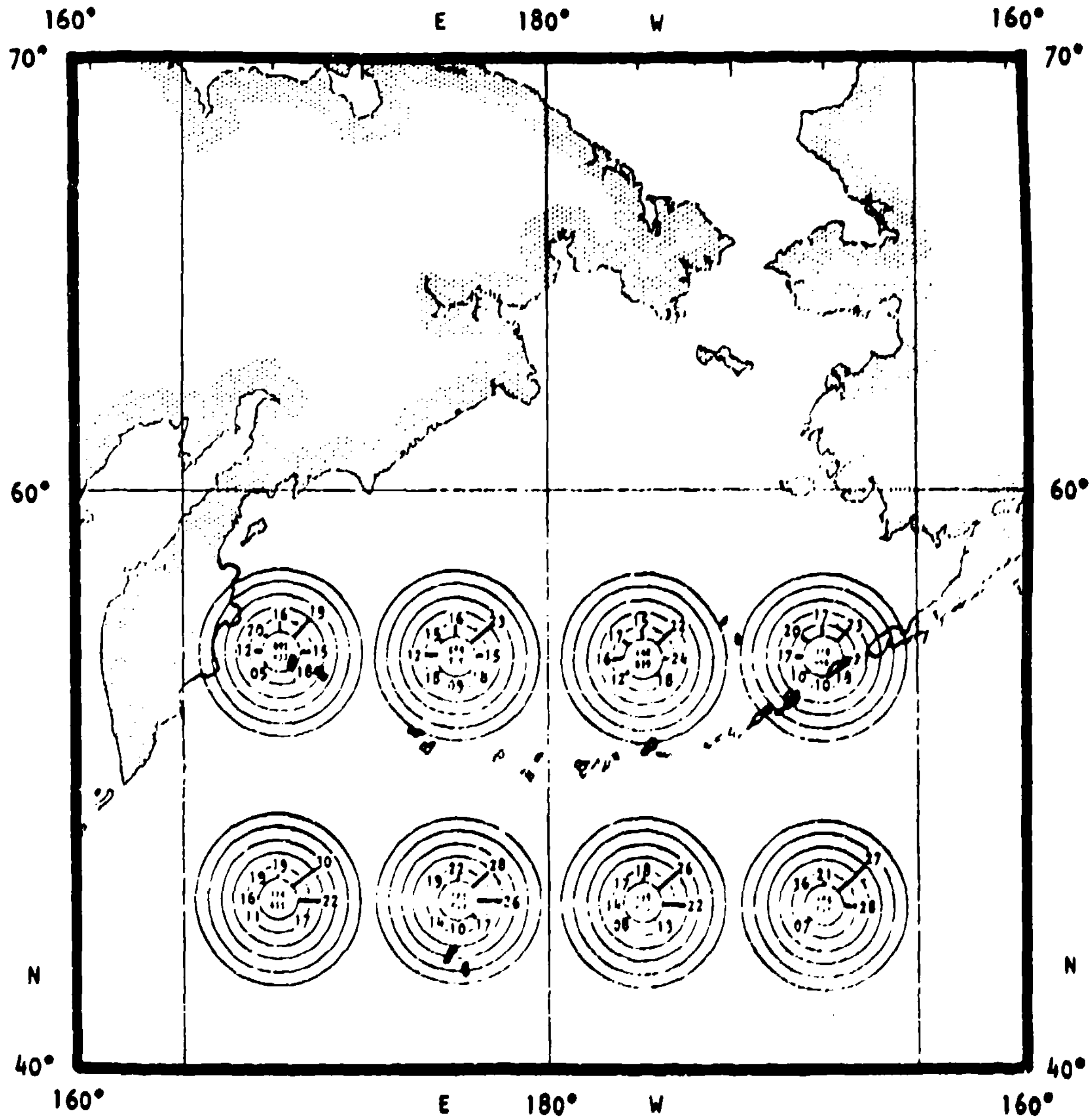


Figure G-11a - Low Pressure Centers

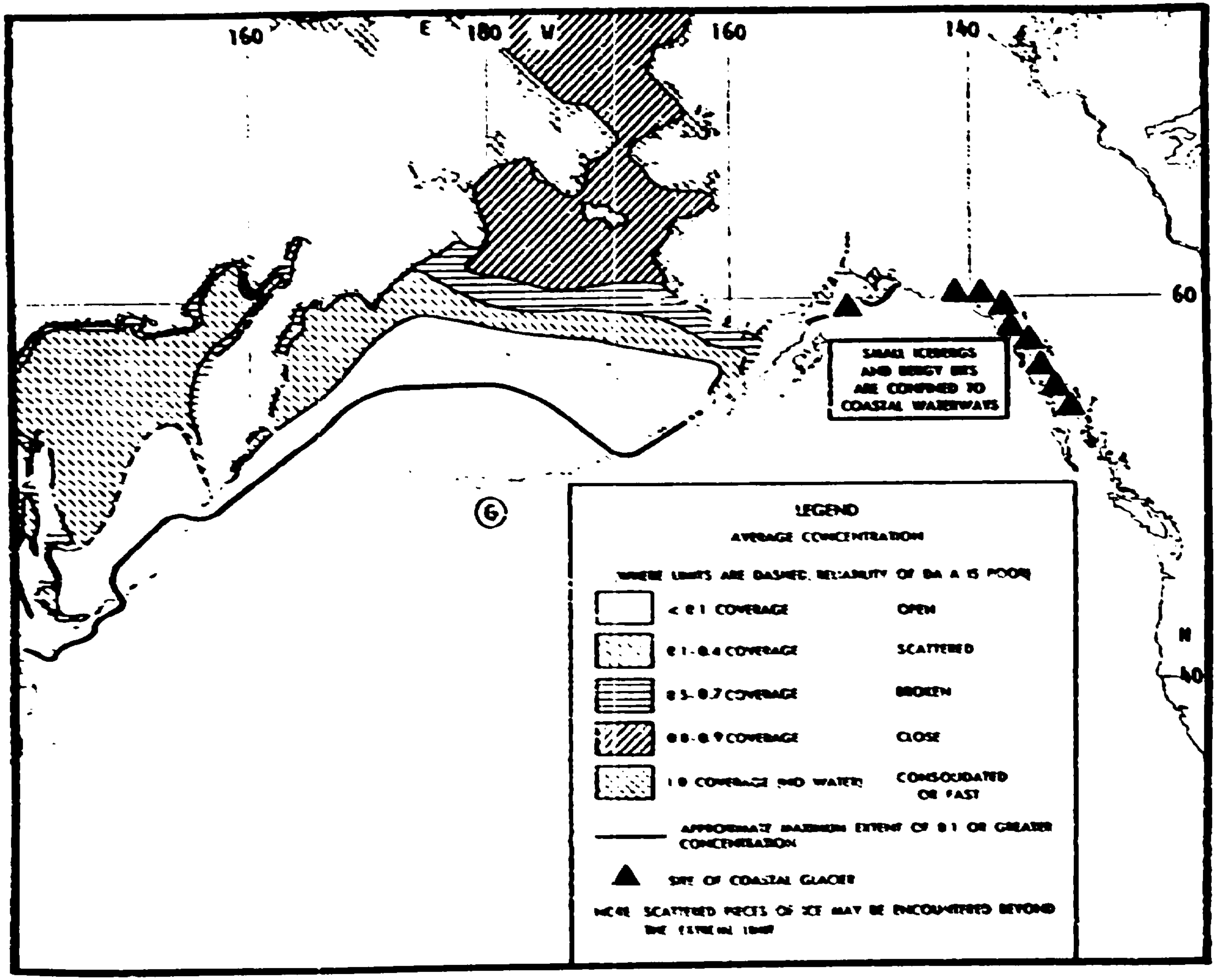


Figure G-12a - Concentration

NO OCCURRENCES REPORTED

Figure G-12b - Icebergs

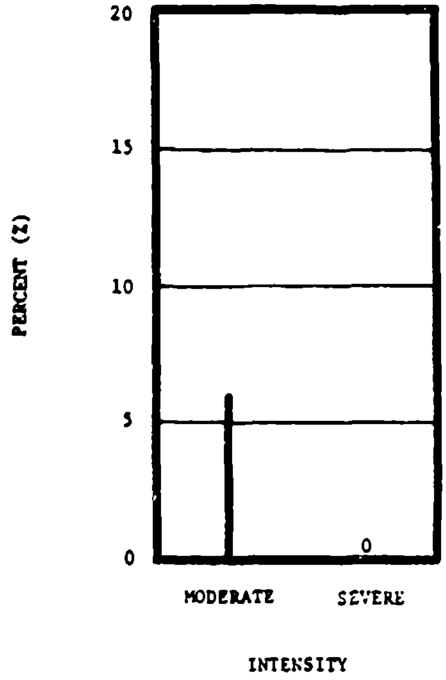


Figure G-13a - Percentage frequency of moderate and severe potential for superstructure icing

APPENDIX H

MARINE CLIMATOLOGY OF THE CARIBBEAN:

20°45' - 21°50'N, 80° - 86°W (OFF CUBA)

PART I. GENERAL MARINE CLIMATOLOGY OF THE CARIBBEAN SEA: 20°45' - 21°50'N, 80-86°W (OFF CUBA)

1. A general climatology for the oceanographic area defined by 20°45' - 21°50'N, 80°-86°W is developed. The area is denoted as Location H on Figure H-1 and is considered important to U.S. Navy operations because of its proximity to Florida and Cuba. The prime data sources are Reference 3, 12, 18, 21, and 22.

2. The major currents of concern here are illustrated in Figure H-1. A branch of the North Equatorial Current flows westward through the South Caribbean at about 1 knot. A second weaker branch is the Antilles Current, which flows northwestward north of the Caribbean Islands at about ½ knot. Both branches join the Gulf Current and flow northward at 2.5 to 2.8 knots, the flow becoming variable near the island of Cuba. Tidal ranges are very small, the maximum seasonal change in high or low tide being generally less than 2 feet.

The ocean currents about Location H tend to move in a southeastward direction, in general, at a speed of less than 0.7 knot. They have a tendency to travel eastward in northern regions and then change to a southwestward direction in the southern regions.

3. The region is located to the southwestern and western side of a clockwise circulation of the middle Atlantic area (commonly referred to as the "Bermuda or Azores High") and lying within the northeast tradewind belt. There occur, during summer months, the "bayamos," which are types of particularly violent thundersqualls consisting of brief but violent blasts of wind accompanied by lightning, thunder, torrential rain and whitened seafoam. Some storms may build into hurricanes (winds of 65 knots or more), causing winds of over 150 knots. In general, hurricanes are considered the most severe climatological occurrence for the area. They are considered hazardous to all forms of surface and air naval operations due to the high winds and seas, torrential rains, disrupted currents, and low visibilities. The frequency of occurrence of such storms in the North Atlantic, Gulf of Mexico, and Caribbean is as low as one storm recorded in 1890 and as high as 21 recorded in 1933. When considering Location H alone, the maximum occurrence is somewhat less. In winter (January) and spring

(April) it is highly unlikely that a hurricane will occur, while in summer (July) there is a slight 1 percent frequency of occurrence, and in fall (October) a more significant 26 percent frequency of occurrence. Unfortunately comprehensive sets of climatological (air and sea) observations during such storms do not exist.

The seasonal variation of mean sea level pressures and mean storm tracks, where known, is shown in Figure H-2. The diurnal pressure variation is generally between 2 and 4 millibars. A fall in pressure of more than 4 millibars should be taken as a warning of the possible development or approach of a tropical storm.

4. Westward (that is, from the east and towards the west) winds predominate from January through September, decrease in August and in September increase again before shifting to a predominately southwesterly wind until January when predominant wind direction shifts back to the west. While westward winds may occur up to 40 percent of the time for any particular month, southward and northwestward winds may account for about 10 to 20 percent each. Throughout the year, westward or southwestward winds are dominant. Gale force winds of 34 knots or more seldom occur. The highest incidence of winds over 17 knots occurs between November and March (up to 30 percent of observations). The lowest mean speeds are observed in July, August and September.

At Location H, winds of 17 knots or more occur 24 percent of the time in winter, 18 percent of the time in spring, 6 percent of the time in summer and 18 percent of the time in fall.

5. The sheltering effect of the land mass to the North of Location H results in waves of generally low height and the sea direction generally coincides with the wind direction. In winter, less than 1 percent of all waves observed exceed 12 feet while the other seasons show even less occurrence, see Figure H-3. Occasional swells from the east and southeast are observed throughout the year and are generally less than 6 feet in height. Unfortunately the higher seas and swells associated with hurricanes are rarely recorded. The most probable wave periods throughout the year are less than 7 seconds. In general, short "choppy" waves should persist at Location H.

6. As a rule, rainfall at Location H occurs at night or in the early morning hours. Heavy and prolonged showers seldom occur. The islands of the Caribbean receive much more rain than the surrounding waters.

7. Fog is rare in this region. However, salt particles thrown up by the sea after a period of prolonged rough seas may form a haze as thick as a light fog. This white-water vapor haze is formed by fine droplets of water with the salt particles as nuclei.

8. The average daily temperature is about 76°F during the winter and 84°F during the summer. Occasionally it exceeds 90°F during the summer. The average humidity is 75 percent, ranging from 60 percent during the day to 90 percent at sunrise. The climate, however, is not oppressive despite high temperatures and high humidity because of the dependable breezes from the tradewinds.

9. The mean sea surface temperatures range between about 82°F in winter and 86°F in fall. Maximum and minimum temperatures vary by only about two degrees throughout the year, with winter showing the greatest difference (4°F).

10. Visibility in the direction of the sun is poor at times due to the presence of the white-water vapor haze. Visibility is always better away from the sun or on days when a cloud cover obstructs the sun's rays. Generally, visibility is greater than 5 nautical miles for 90 percent of observations throughout the year. There are few readings for visibility of less than one mile. In the month of worst visibility (April), 2 percent of observations are between 1 and 2 nautical miles, 8 percent are between 2 and 5 nautical miles, 60 percent are between 5 and 10 nautical miles and 30 percent between 10 and 25 miles.

11. The maximum number of daylight hours is slightly more than 13 hours occurring in mid-June. The minimum number of daylight hours is about 11 hours, occurring in mid-December.

12. At Location H, water depth is greater than 2000 fathoms and the bottom is mostly mud mixed with sand. To the north of Location H, the sea floor rises to 500 fathoms and emerges as the Isla de Pinos and a string of much smaller islands just south of western Cuba. Reefs should be expected near these islands. To the south of Location H, the sea floor rises to a depth of 100 to 500 fathoms in several places while to the west, in the Yucatan

channel, a passage of a depth of about 500 fathoms exists. Man-eating fish such as shark and barracuda infest these waters.

13. Salinity is almost 36 parts per thousand. Seasonal variation is generally small.

JANUARY - MARCH JULY - AUGUST

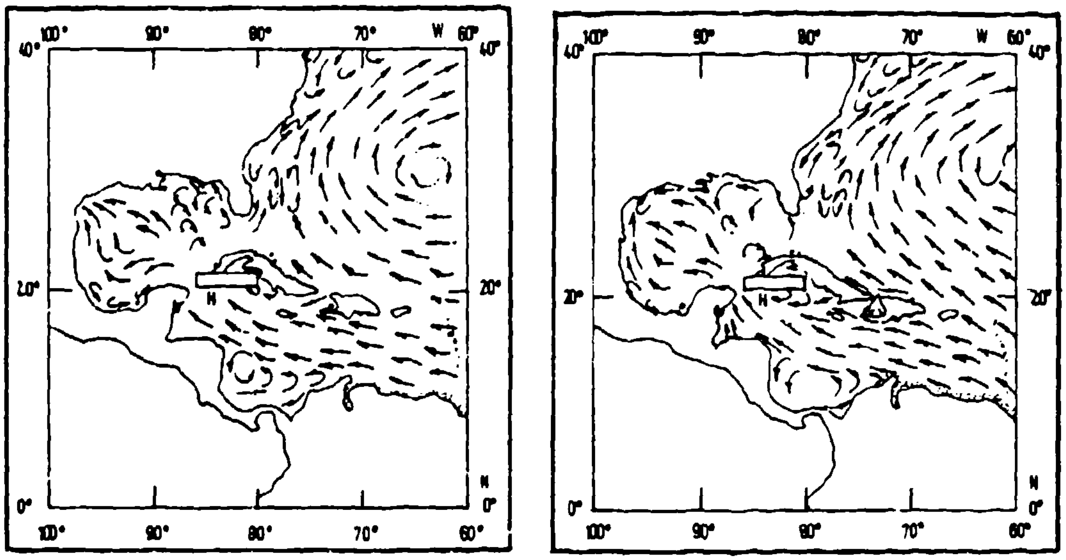
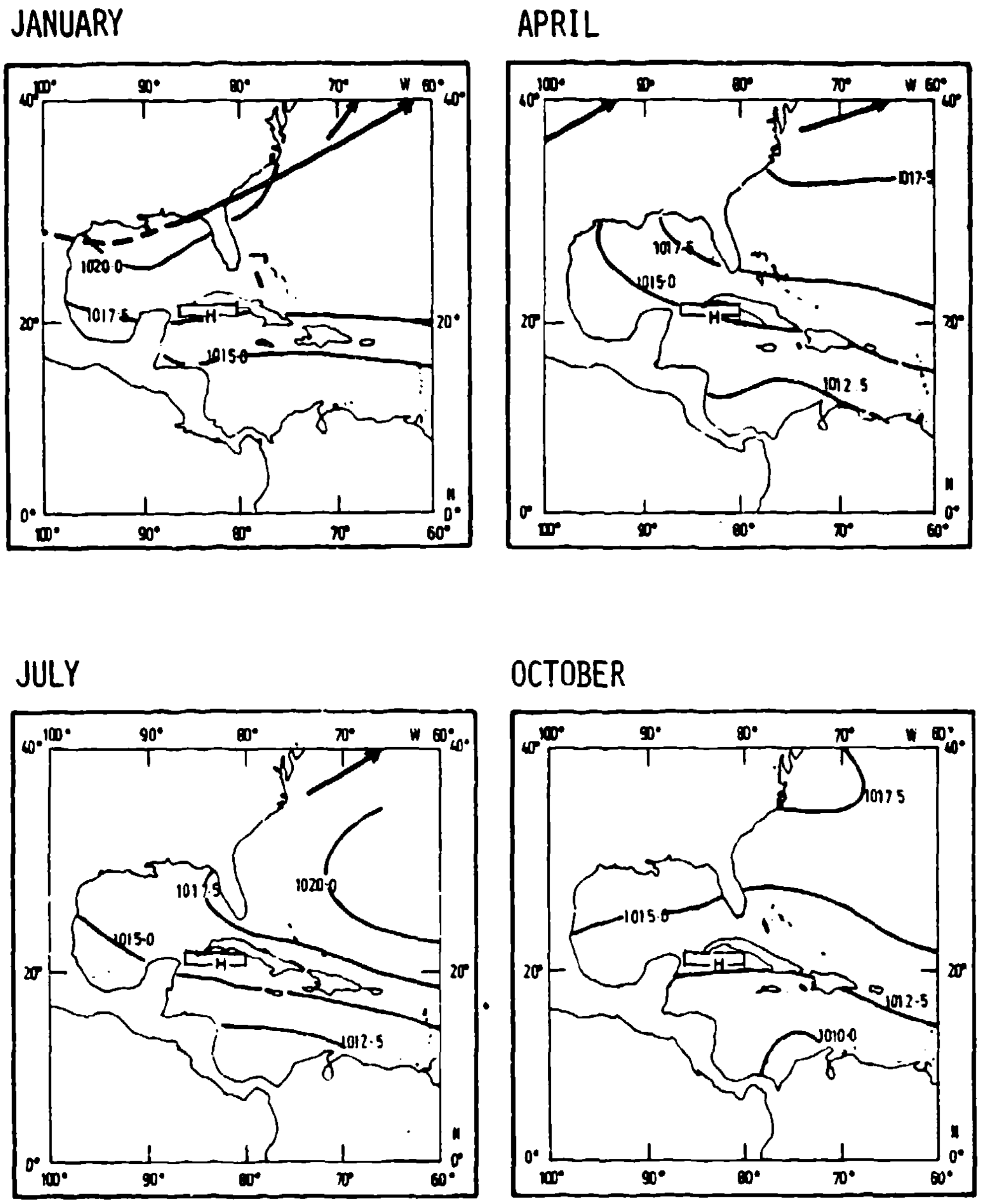


Figure H-1 - Generalized Ocean Currents for the Caribbean



——— Mean Sea Level Pressure in Millibars

———► Primary track, along which there has been maximum concentration of individual storm center paths

- - - - -► Secondary track, along which there has been moderate concentration of individual storm center paths

Figure H-2 - Seasonal Mean Sea Level Pressures and Storm Tracks

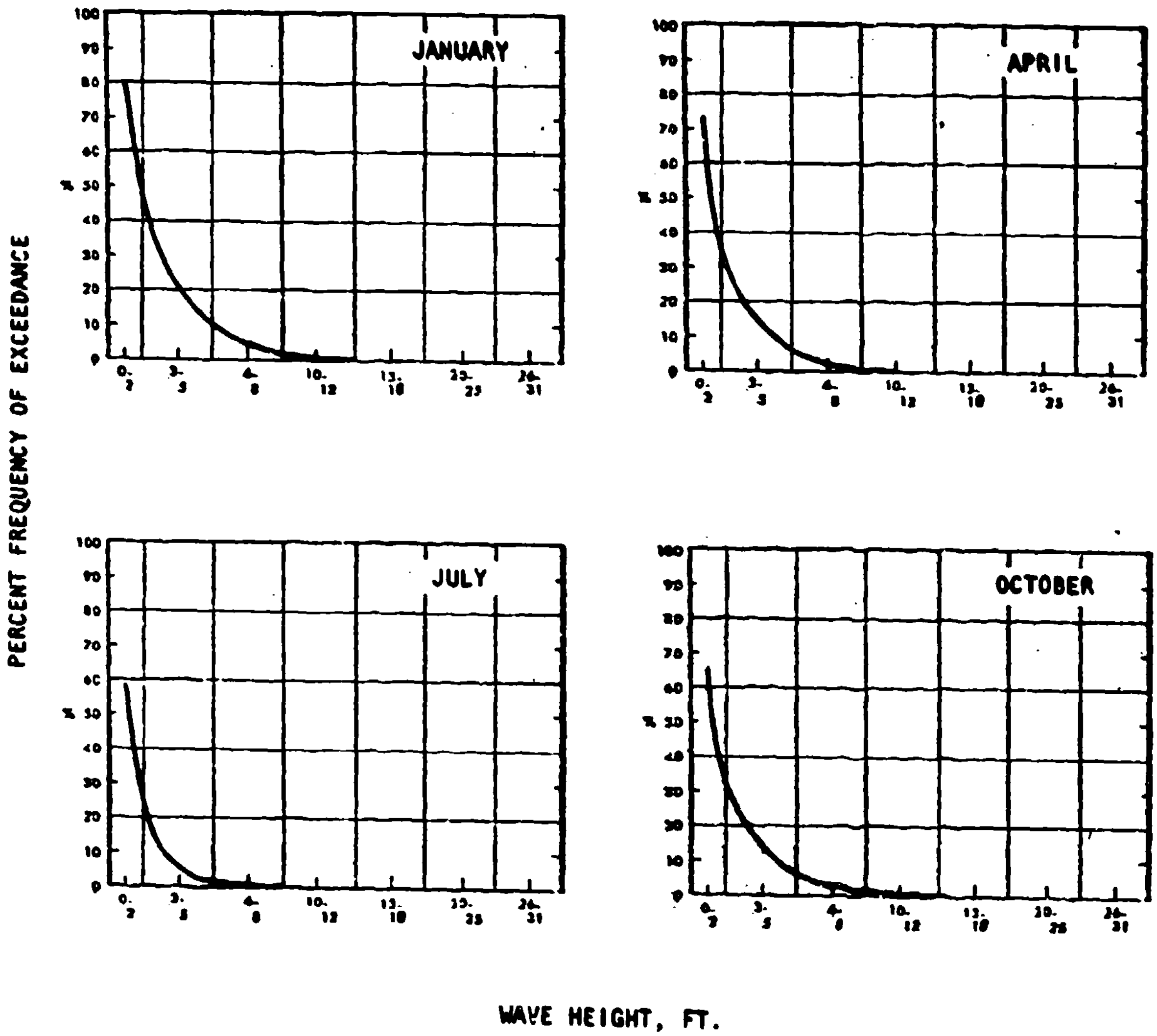


Figure H-3 - Seasonal Wave Height Exceedances

PART II. WINTER (JANUARY) CLIMATOLOGY OF THE CARIBBEAN: 20°45' - 21°50'N, 80° - 86°W (OFF CUBA)

The following data graphs are derived primarily from Reference 22 for the worst wind/wave season, January. Figure H-4a is adopted from Reference 18. Figures H-11a and H-11b are adopted from Reference 3.

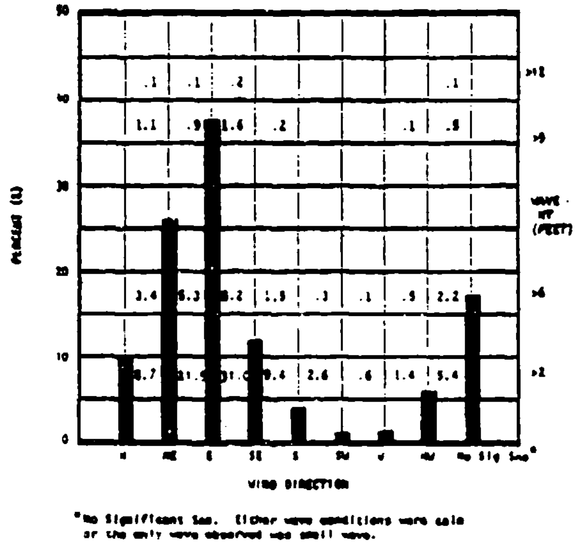


Figure H-1a - Sea Height by Wind Direction

NOT AVAILABLE

Figure H-1b - Sea Height - Cumulative Distribution

NOT AVAILABLE

Figure H-1c - Mean Sea Height by Wind Speed

NOT AVAILABLE

Figure H-1d - Swell Height by Direction

NOT AVAILABLE

Figure H-1e - Swell Height - Cumulative Distribution

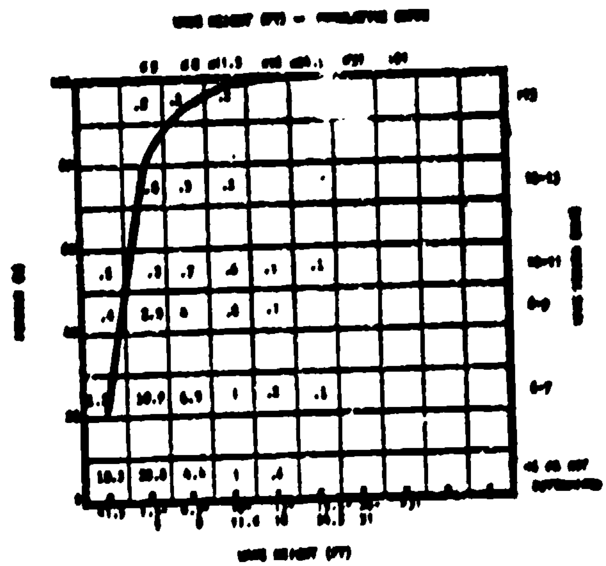


Figure H-1f - Wave Height and Period

NOT AVAILABLE

Figure H-1g - Return Periods for High Waves

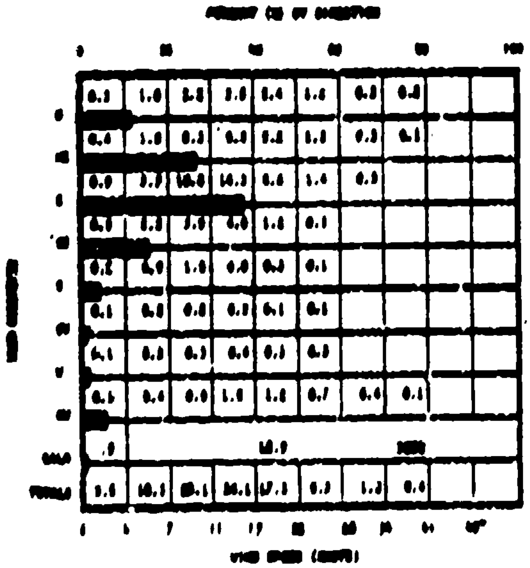


Figure H-2a - Wind Speed by Direction

NOT AVAILABLE

Figure H-2b - Return Periods for Maximum Sustained Winds

NOT AVAILABLE

Figure H-2c - Wind Direction - Diurnal Variations

NOT AVAILABLE

Figure H-2d - Wind Speed - Diurnal Variation

NOT AVAILABLE

Figure H-2e - Gale Persistence

NOT AVAILABLE

Figure H-2f - Wind Speed
Diurnal Variation

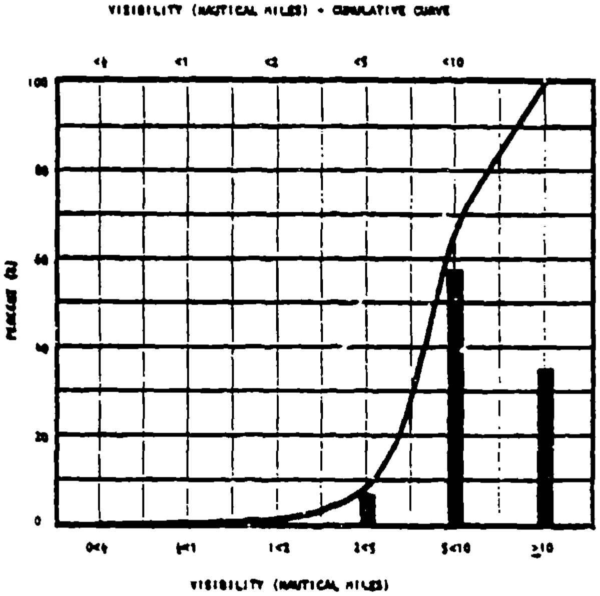


Figure H-3a - Visibility - Cumulative Distribution

NOT AVAILABLE

Figure H-3b - Visibility - Diurnal Variation

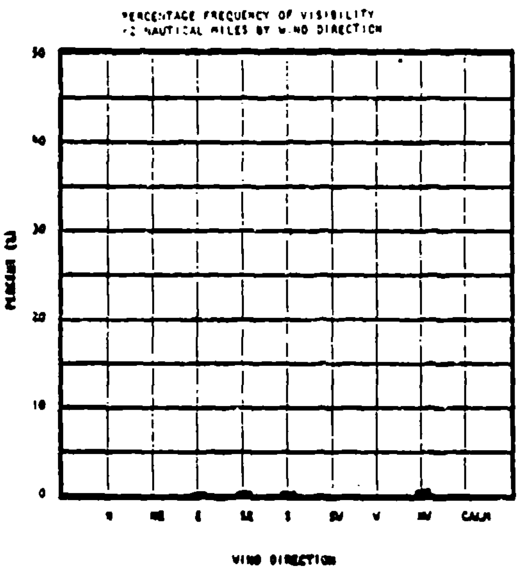


Figure H-3c - Visibility by Wind Direction

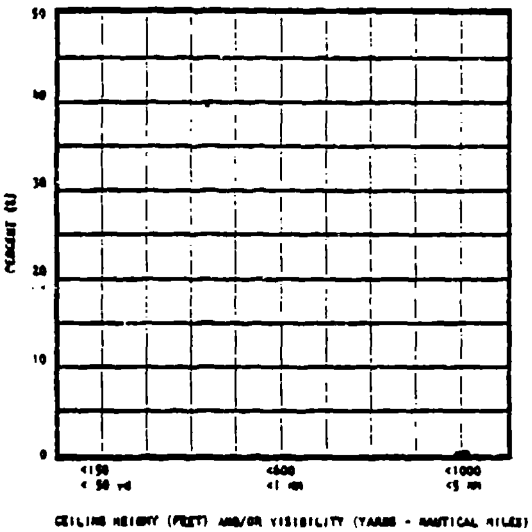
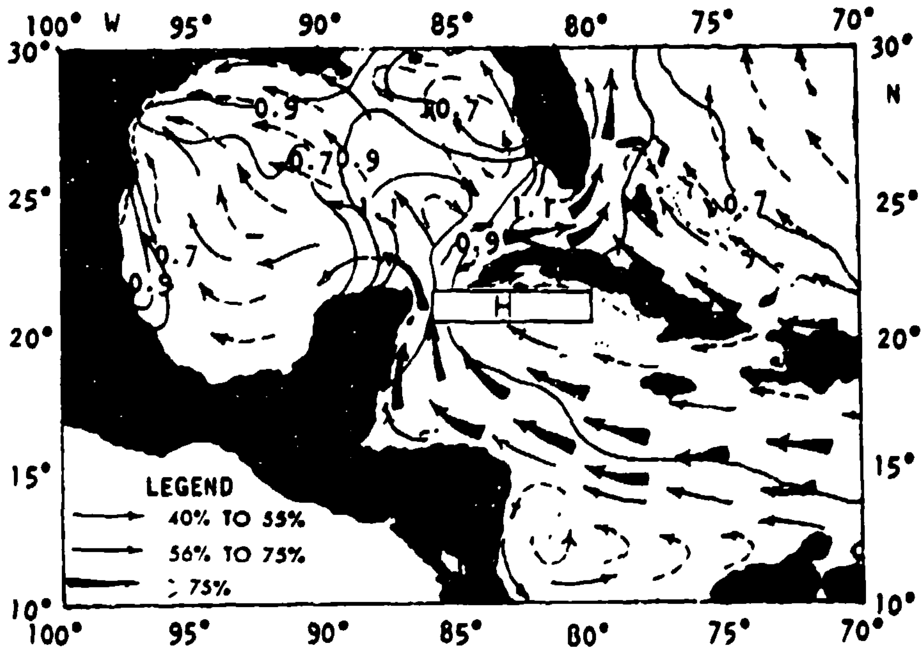


Figure H-3d - Low Visibility and/or Ceiling Height

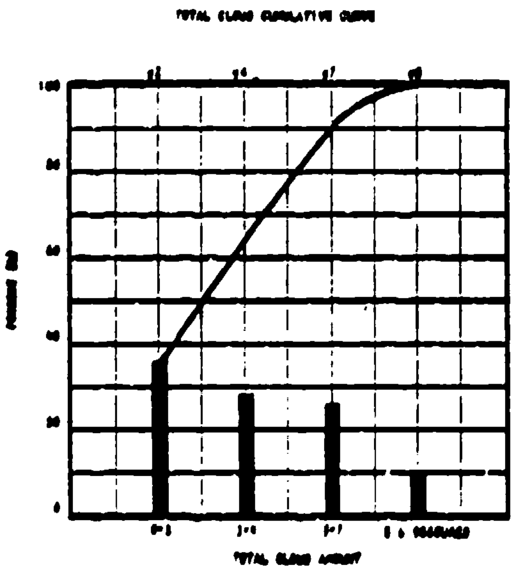
NOT AVAILABLE

Figure H-3e - Visibility Persistence



NOTE: ADDITIONAL CONTOUR LINES HAVE BEEN OMITTED TO THE SOUTH AND EAST OF THE FLORIDA PENINSULA FOR CLARITY. THESE ADDITIONAL CONTOURS REACH A MAXIMUM OF 2.5 KNOTS TO THE EAST OF THE PENINSULA.

Figure H-4a - Mean Surface Current Speeds and Prevailing Directions



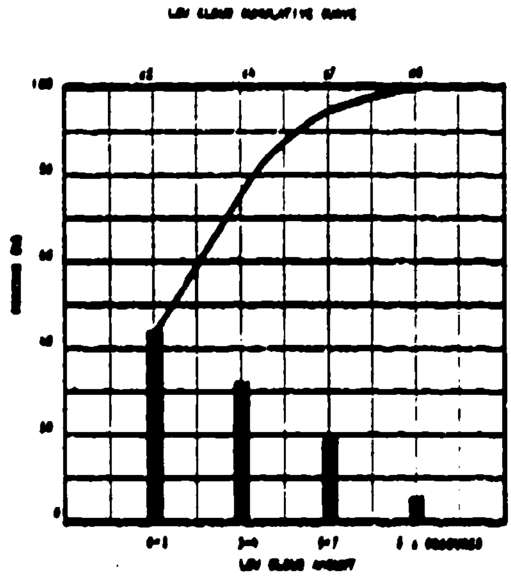


Figure H-5a - Cloud Amounts - Cumulative Distribution

NOT AVAILABLE

Figure H-5b - Mean Cloud Amounts

NOT AVAILABLE

Figure H-5c - Good Cloud Conditions - Diurnal Variation

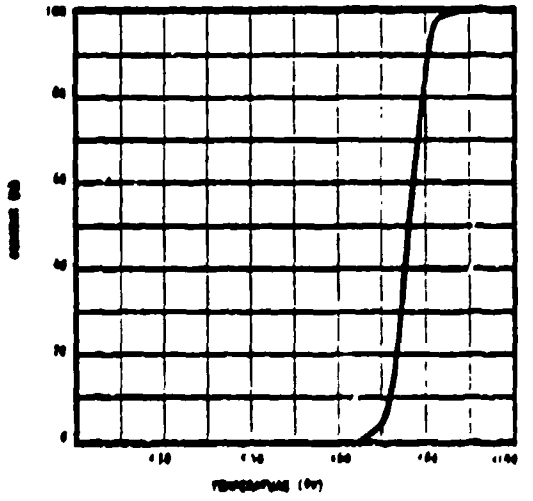


Figure H-6a - Air Temperature - Cumulative Distribution

NOT AVAILABLE

Figure H-6b - Air Temperature - Diurnal Variation

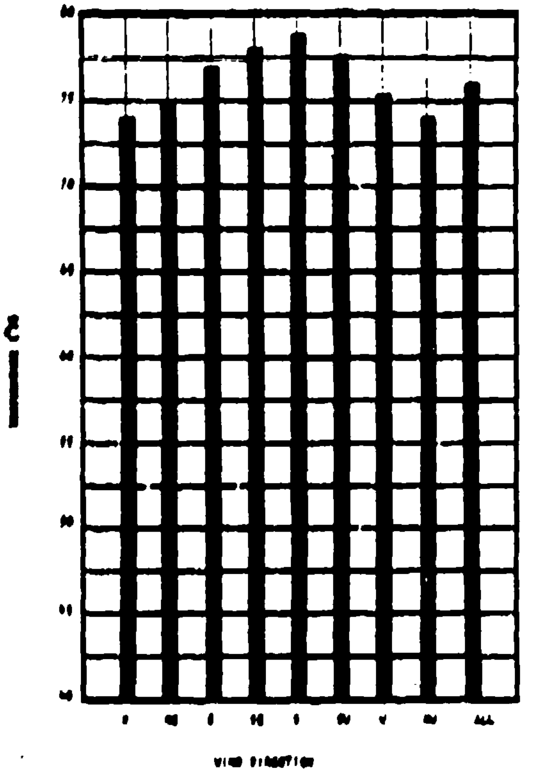


Figure H-6c - Mean Air Temperature by Wind Direction

NO OCCURRENCES REPORTED

Figure H-6d - Air Temperature and Gales

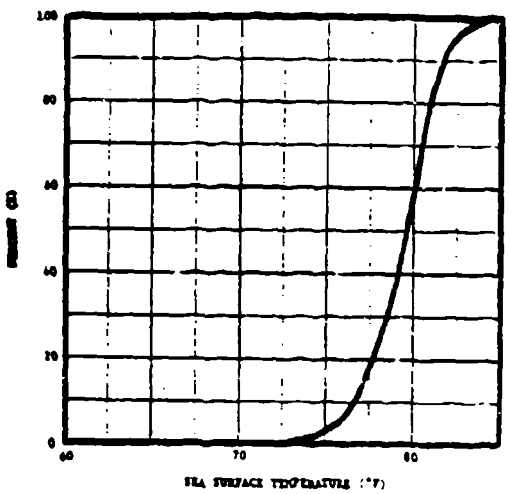


Figure H-6e - Sea Surface Temperature

NOT AVAILABLE

Figure H-6f - Relative Humidity Diurnal Variation

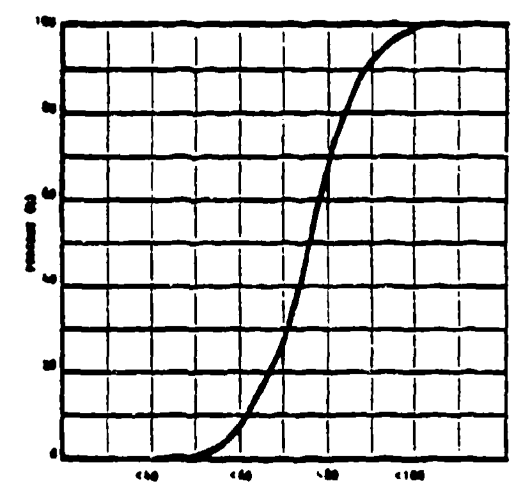


Figure H-6g - Relative Humidity Cumulative Distribution

NOT AVAILABLE

Figure H-7a - Precipitation
by Type

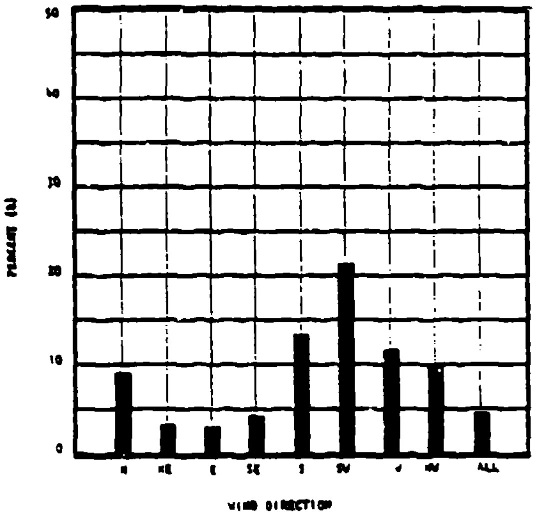


Figure H-7b - Precipitation
by Wind Direction

NOT AVAILABLE

Figure H-7c - Precipitation
Diurnal Variation

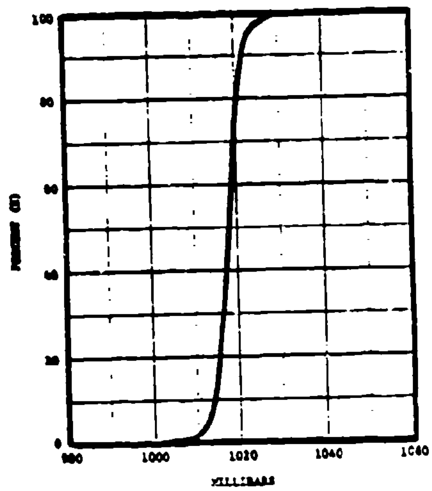


Figure H-8a - Sea Level Pressure -
Cumulative Distribution

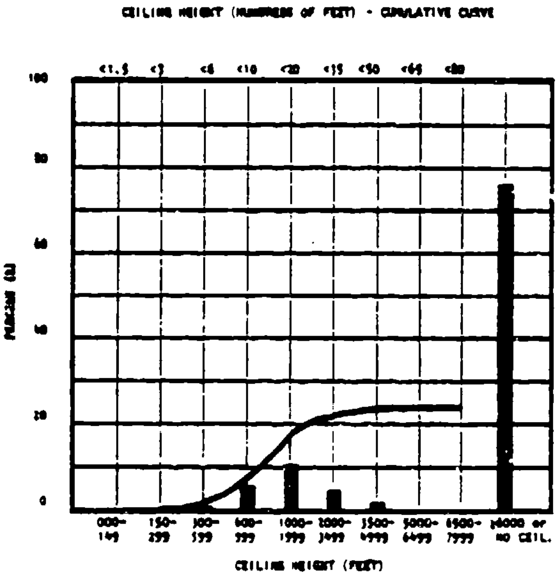


Figure H-9a - Ceiling Height

NOT AVAILABLE

Figure H-9b - Ceiling Height - Diurnal Variation

NOT AVAILABLE

Figure H-10a - Fog versus
Wind Direction

NOT AVAILABLE

Figure H-10b - Fog versus Air -
Sea Temperature Difference

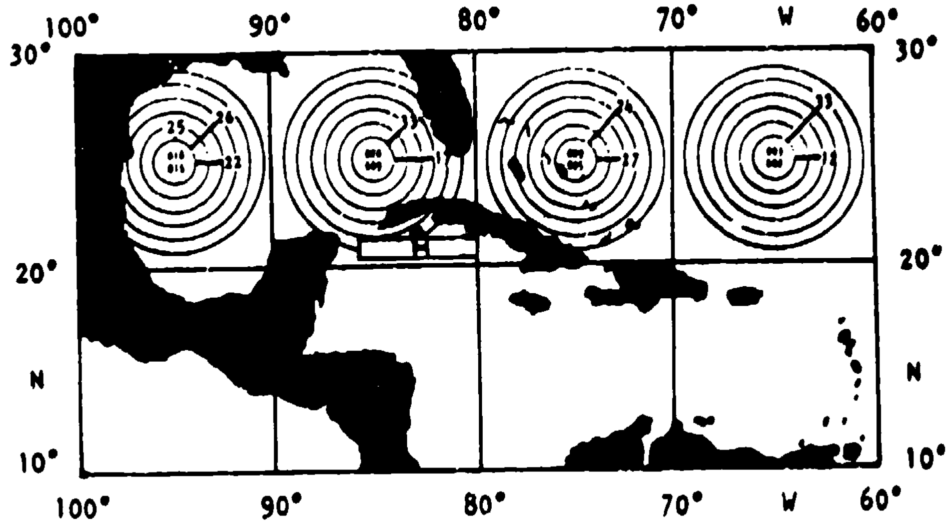


Figure 11a - Low Pressure Centers

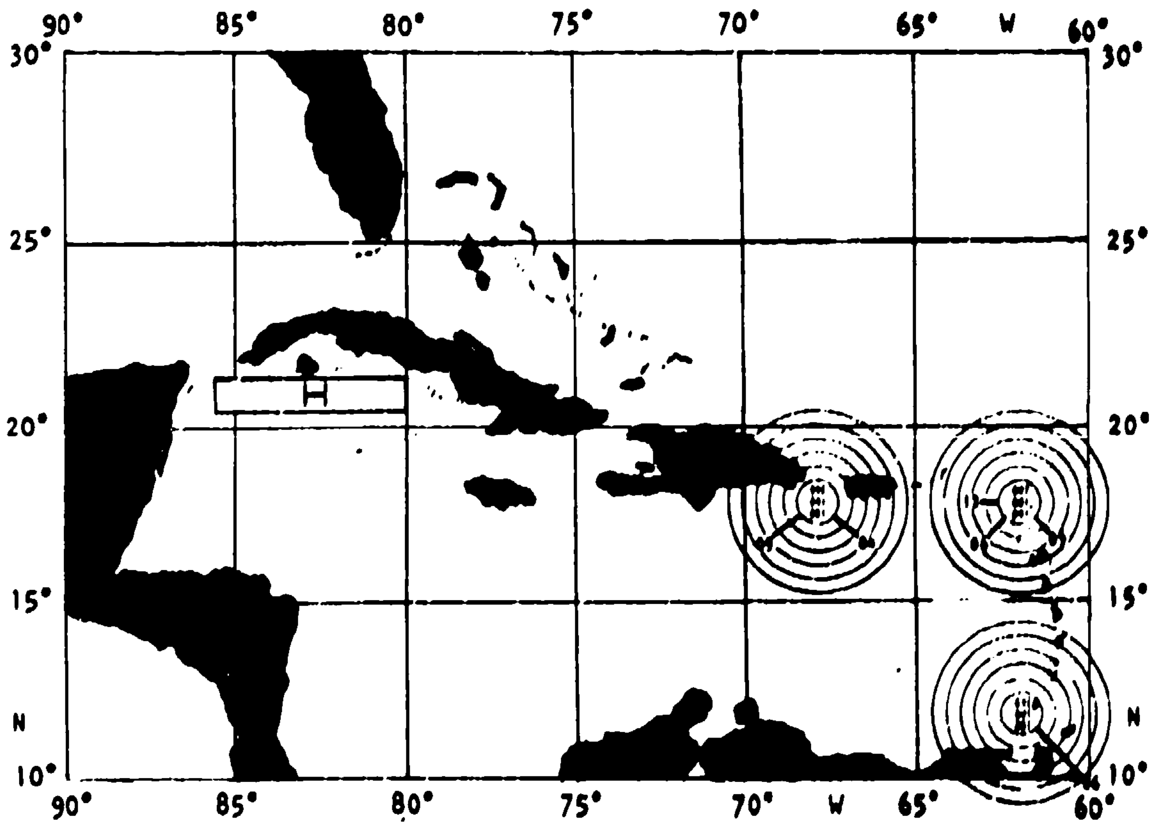


Figure 11b - Tropical Cyclones

NOT AVAILABLE

Figure 11c - Thunderstorms

NO OCCURRENCES REPORTED

Figure H-12a - Concentration

Figure H-12 b - Icebergs

Figure H-13a - Percentage frequency
of moderate and severe potential
for superstructure icing

APPENDIX I

MARINE CLIMATOLOGY OF THE STRAIT OF MALACCA:

0°N, 106°E (OFF SINGAPORE)

PART I. GENERAL MARINE CLIMATOLOGY OF THE STRAIT OF MALACCA: 0°N, 106°E (OFF SINGAPORE)

1. A general climatology for the oceanographic area defined by 0°N, 106°E is developed. The area, to the southeast of the Strait of Malacca, is denoted as Location I on Figure I-1 and is considered important to U.S. Navy operations because of its proximity to Singapore, as well as to Southeast Asia and Australia. The prime data sources are References 5, 6, 16, 23, and 24.

2. The characteristic features of the climate in the vicinity of Singapore and Location I are uniform temperature and pressure, and high humidity and copious rainfall. There is not a large temperature variation throughout the year, nor are there noticeable dry and wet seasons as is usual in tropical areas. The Strait of Malacca is within the limits of the northeast (November to April) and southwest (May to October) monsoons of the Indian Ocean. However, these monsoons are only regular when they are at their height in the adjacent seas. Winds are generally moderate and variable in the strait itself and last only part of the day, except near Singapore where monsoons become more regular. During the southwest monsoon the weather is cloudy and rainy.

3. The ocean currents of concern here are illustrated on Figure I-1. During the northeast monsoon (January) and the transition period (April) to the southwest monsoon, the current about Location I flows from the northwest. During the southwest monsoon (July) the current flows from the southeast. During the transition to the northeast monsoon (October) the current flows from the north. Regardless of direction, the currents passing through Location I are generally traveling at less than 1 knot.

4. There are no large pressure variations throughout the year at Location I, see Figure I-2. Extreme mean sea-level values recorded over a period of 30 years are 1002.0 and 1016.9 millibars.

5. Gale force winds of 34 knots or more have occasionally been observed at Location I during the northeast (January) and southwest (July) monsoons. The transition months generally have lighter winds. During the northeast monsoon, 92 percent of observed winds are less than 17 knots and are primarily from the northwest, north, and northeast. During the southwest

monsoon, 96 percent of the winds are less than 17 knots and are primarily from the east, southeast and south. During the transition months the 98 to 99 percent of the winds are less than 17 knots and the direction is more variable.

6. Generally, it is expected that sea direction will coincide with wind direction at Location I. Due to the landlocked position of the location, swells are not expected. During the northeast monsoon, no waves exceeding 7 feet have been observed and the periods are always less than 9 seconds. During the southwest monsoon, somewhat higher waves, e.g., up to 9 feet, have been observed, but the periods never exceed 7 seconds. These slightly steeper waves may be caused by somewhat more severe but less persistent winds during the southwest monsoon. During the April transition period, no waves over 6 feet have been observed and the periods are always 9 seconds or less. During the October transition period, waves of up to 7 feet in height and occasionally periods greater than 9 seconds have been observed. Figure I-3 illustrates the seasonal variation of wave height at Location I.

7. Rainfall can take place at any time in the general area. There is an average of about 180 rainy days per year at Singapore and the annual rainfall is 95 inches or more. Therefore, over the sea at Location I, large amounts of rain should be expected.

There is no distinct dry or wet season, though a greater amount of precipitation is observed with the northeast monsoon (14 percent).

Thunderstorms are observed throughout the year, and most commonly during the southwest monsoon (6.3 percent of observations). Accompanying these storms may be a sharp drop in temperature and a sudden rise in barometric pressure.

8. Though Location I is located near the Equator, temperatures are not very high. They range from a daily mean of 80°F in January to more than 82°F in April and July. The mean yearly difference between day and night temperature is on the order of 2°F.

Relative humidity is high and persistent at Location I being always above 80 percent.

9. Fog has occasionally been observed at Location I. Haze extending to about 5000 feet throughout the year is most frequent in the transition

month of October (4.5 percent of observations) and is associated with dry spells and a temperature inversion.

10. Mean sea surface temperature is about 83°F throughout the year, and increases slightly between April and July to about 86°F. The minimum temperature recorded in nearby open waters is about 75°F in January.

11. Location I lies directly on the Equator and daylight hours are consistently about 12 hours throughout the year.

12. Generally, visibility is more than 5 nautical miles for 95 percent of the year. Visibility for the worst month (October) is 2 percent between 1 and 2 nautical miles, 2 percent between 2 and 5 nautical miles, 33 percent between 5 and 10 nautical miles and 63 percent over 10 nautical miles. An occasional closing of weather (0.5 percent) lowers visibility to one-half a nautical mile or less throughout the year. At the best (April), visibility of more than 10 nautical miles is observed 78 percent of the time.

13. The water depth about Location I is a shallow 100 fathoms or less.

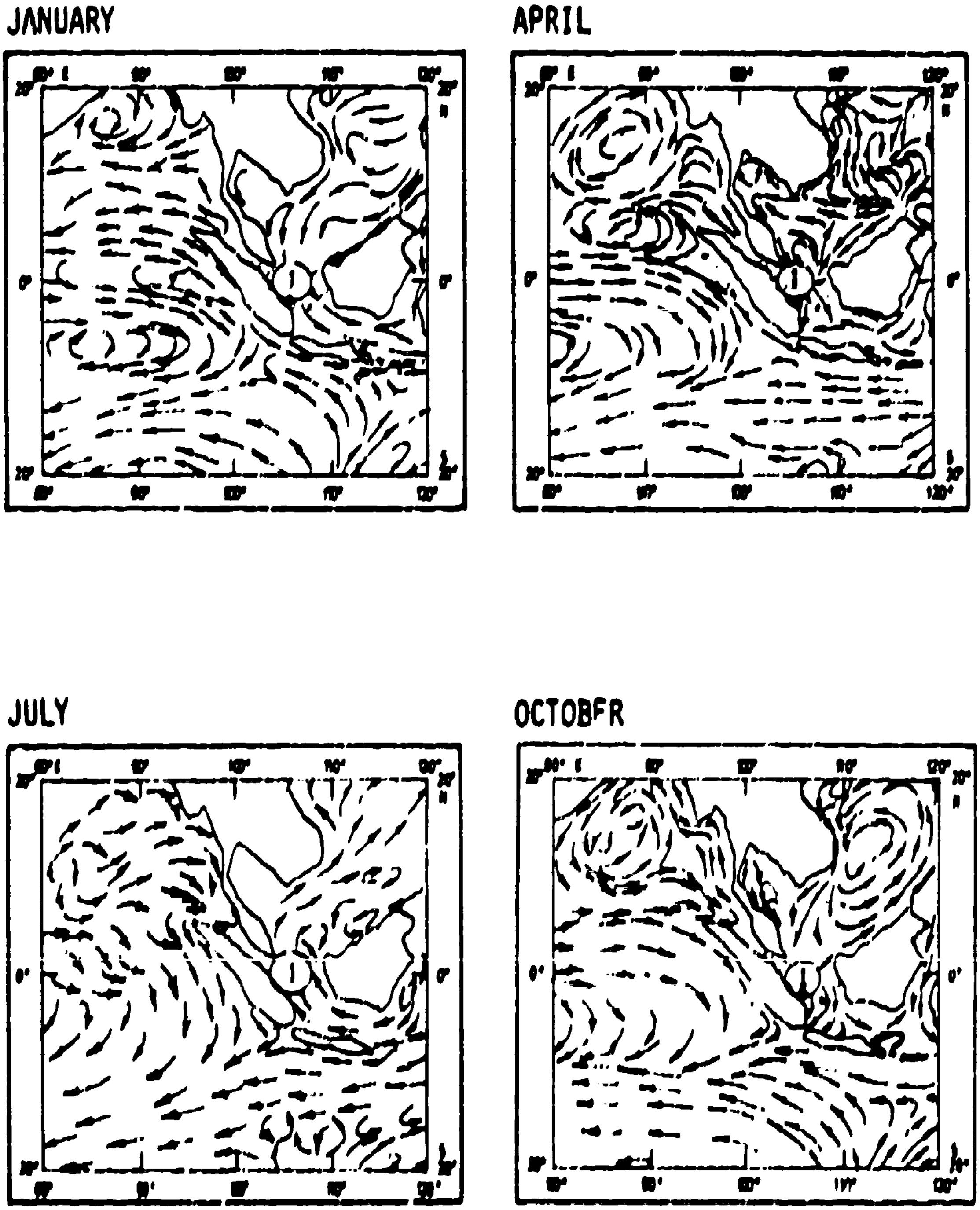
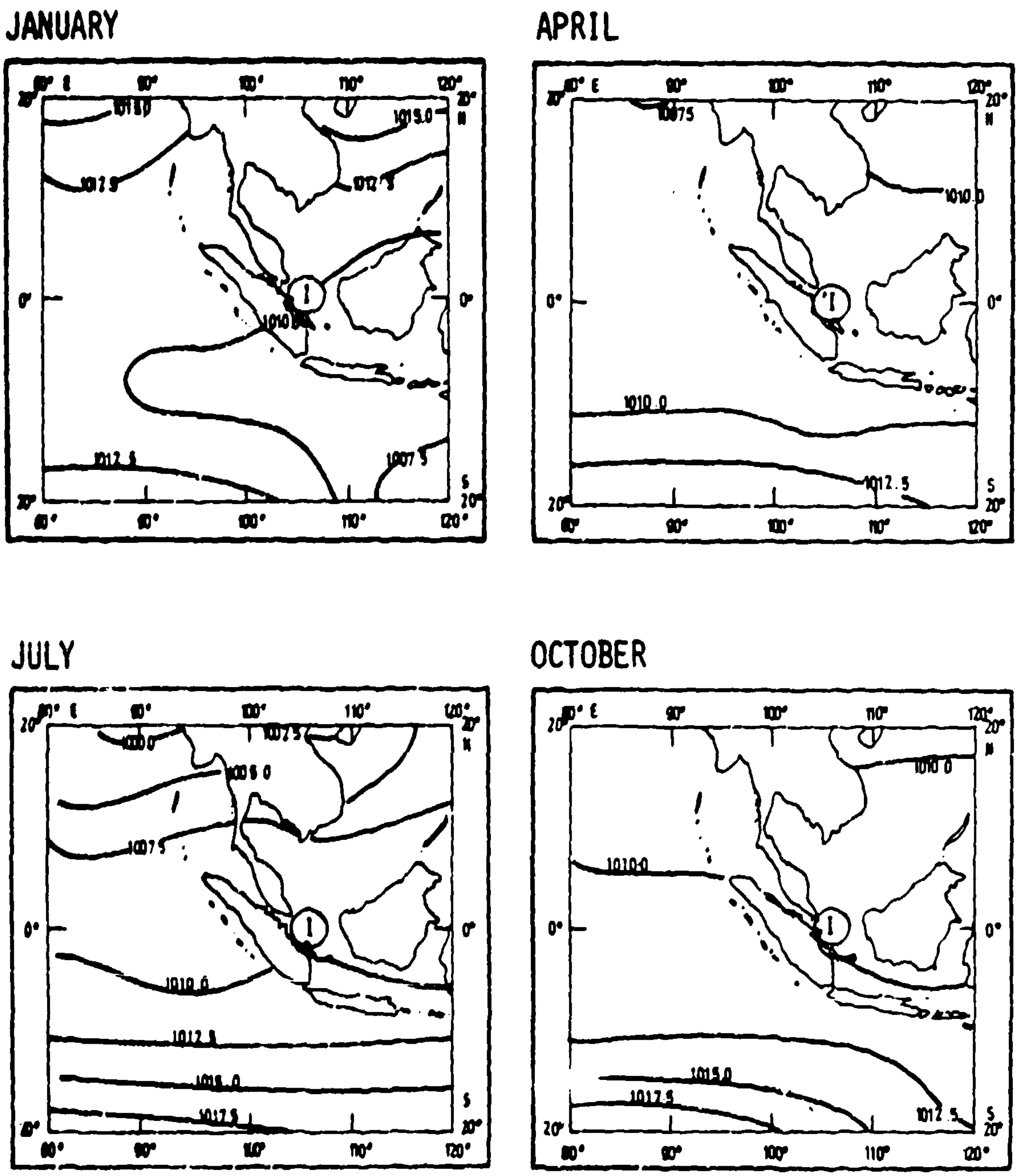


Figure I-I - Generalized Ocean Currents for the South China Sea and parts of the Indian Ocean



—————— Mean Sea Level Pressure in Millibars

Figure 1-2 - Seasonal Mean Sea Level Pressures

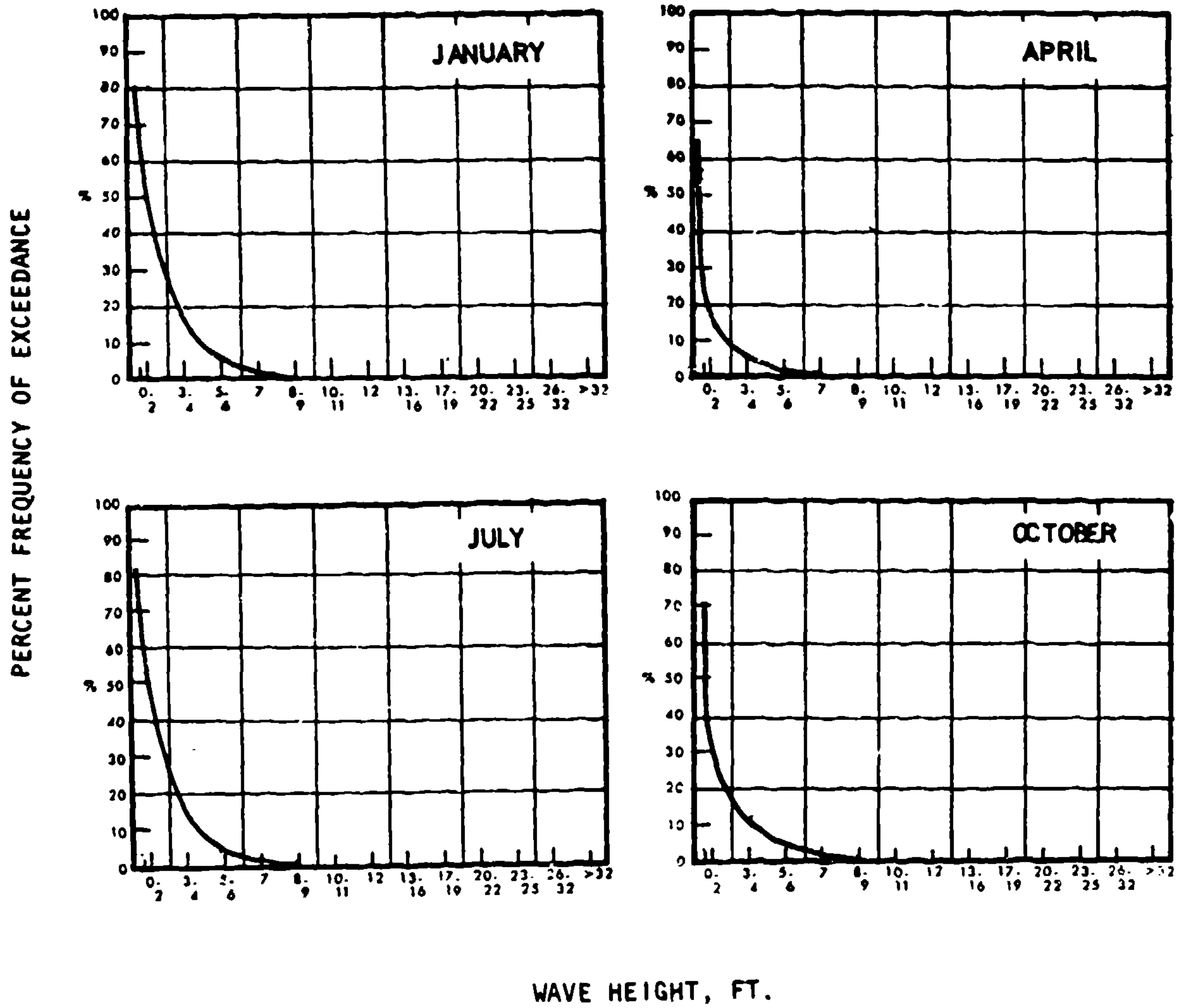


Figure I-3 - Seasonal Wave Height Exceedances

PART II. WINTER (JANUARY) CLIMATOLOGY OF THE STRAIT OF MALACCA: 0° N, 106°E (OFF SINGAPORE)

The following data graphs are derived primarily from Volume 1 of the Indonesian Coastal Marine Areas (Area 5) of Reference 5 for the worst wind/wave season, January. Figure I-4a is adopted from Reference 16.

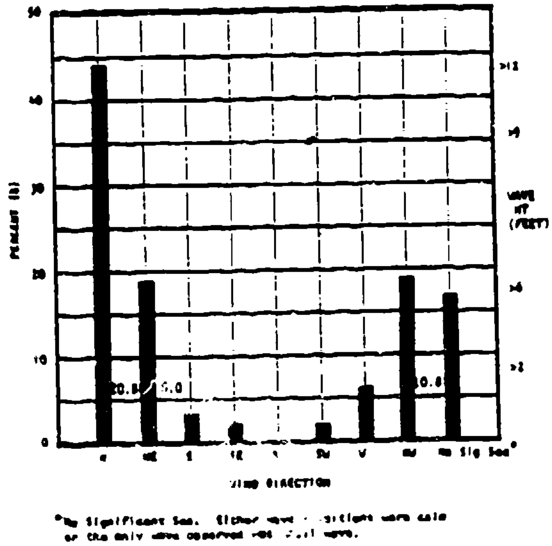


Figure 1-1a - Sea Height by Wind Direction

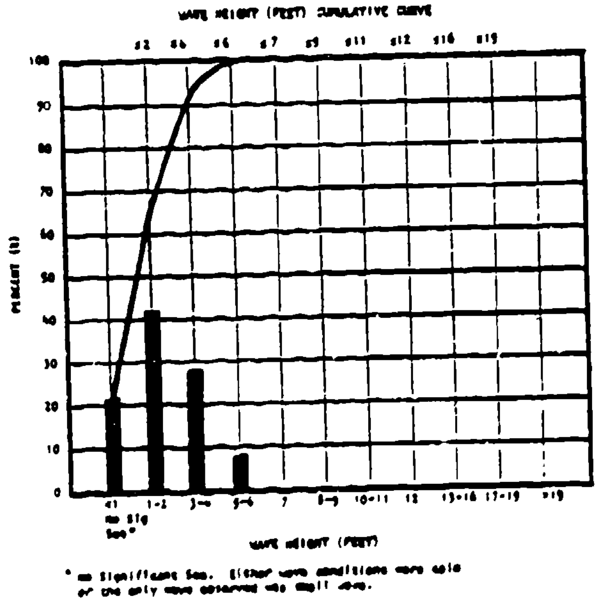


Figure 1-1b - Sea Height - Cumulative Distribution

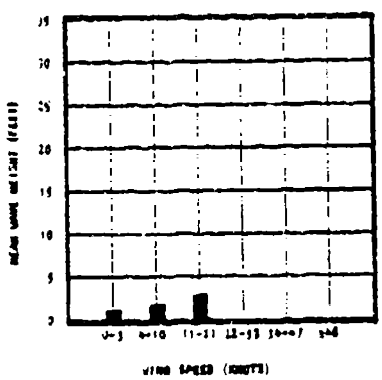


Figure 1-1c - Mean Sea Height by Wind Speed

NOT AVAILABLE

Figure 1-1d - Swell Height by Direction

NOT AVAILABLE

Figure 1-1e - Swell Height - Cumulative Distr.‿ution

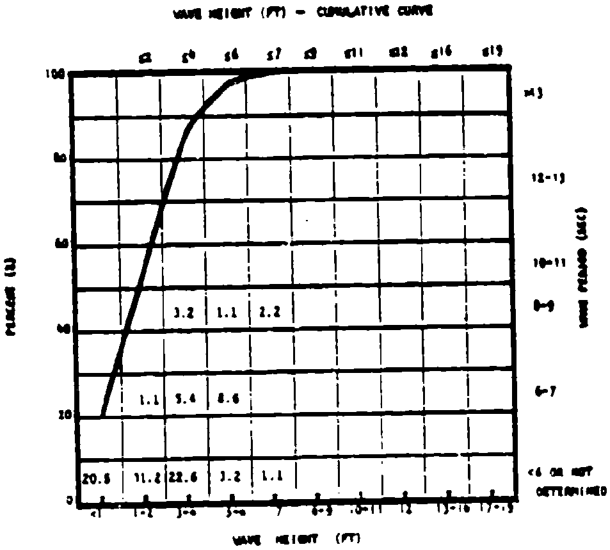


Figure 1-1f - Wave Height and Period

NOT AVAILABLE

Figure 1-1g - Return Periods for High Waves

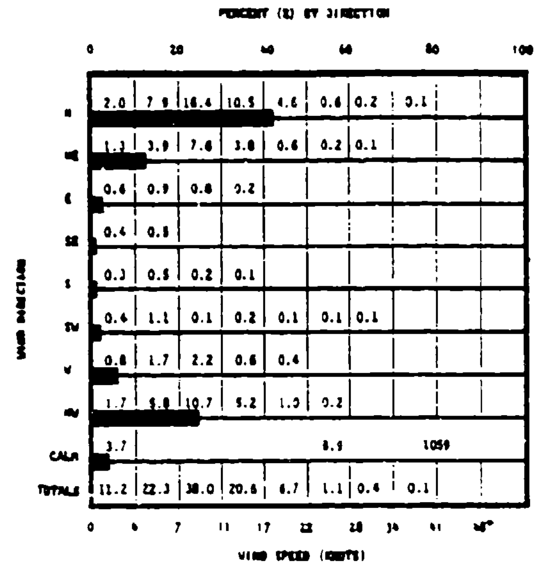


Figure I-2a - Wind Speed by Direction

NOT AVAILABLE

Figure I-2b - Return Periods for Maximum Sustained Winds

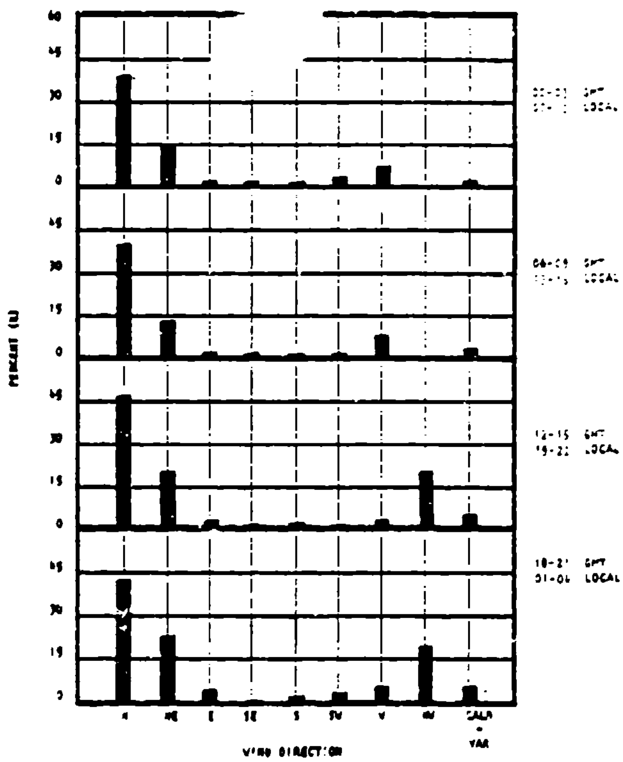


Figure I-2c - Wind Direction - Diurnal Variations

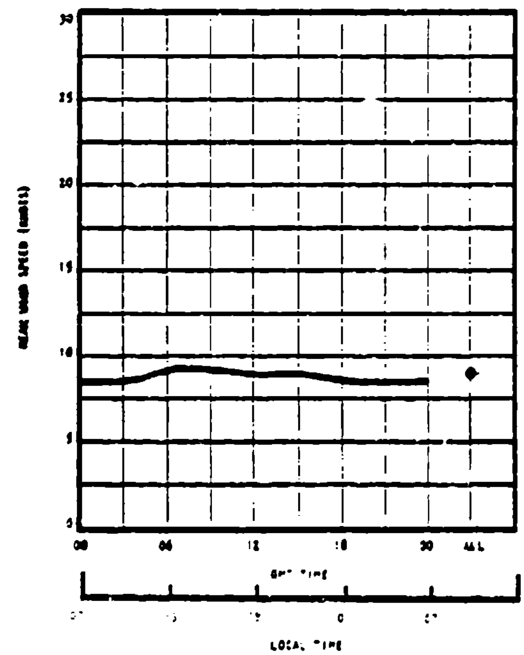


Figure I-2d - Wind Speed - Diurnal Variation

NOT AVAILABLE

Figure 1-2e - Gale Persistence

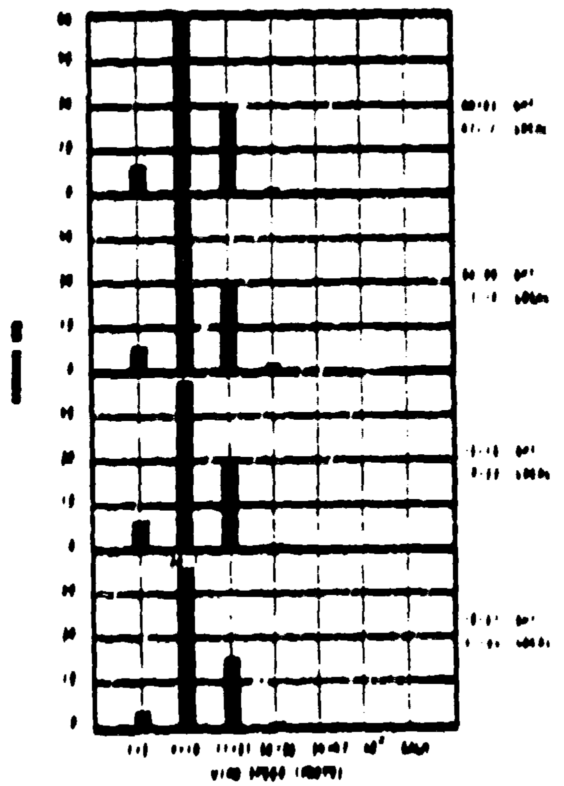


Figure 1-2f - Wind Speed
Diurnal Variation

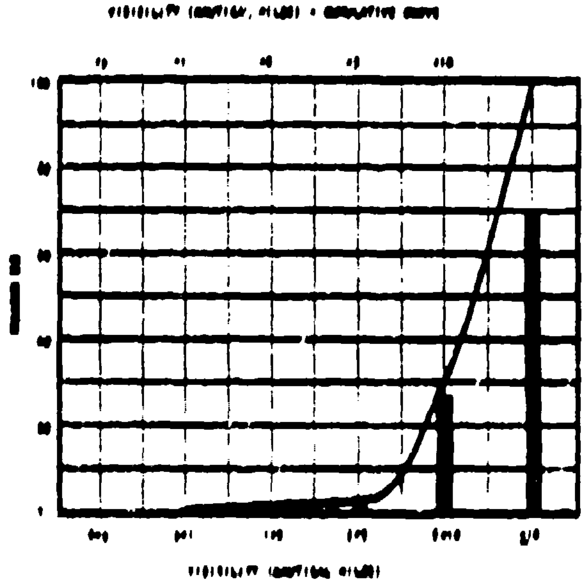


Figure I-3a - Visibility - Cumulative Distribution

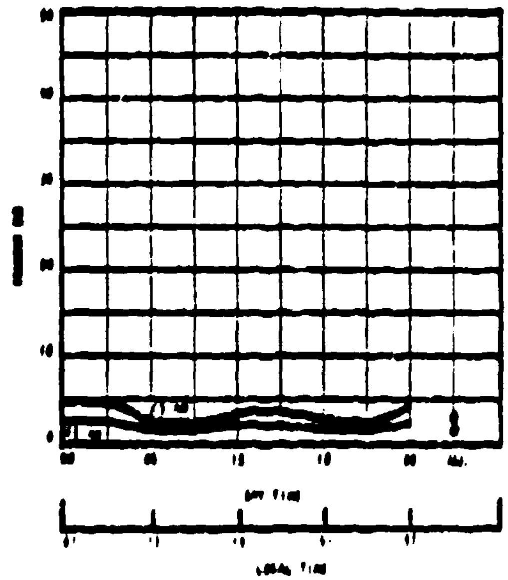


Figure I-3b - Visibility - Diurnal Variation

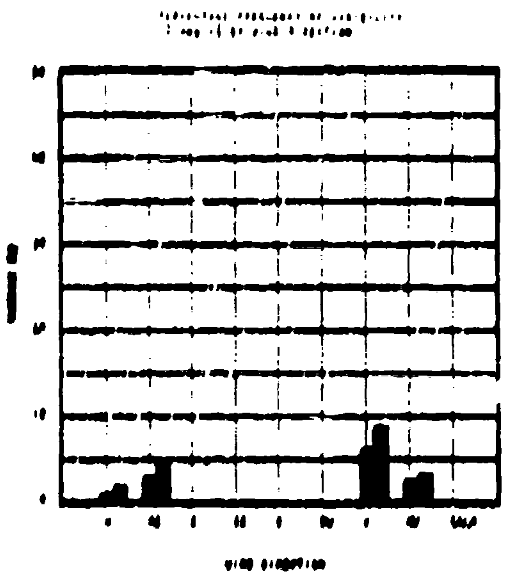


Figure I-3c - Visibility by Wind Direction

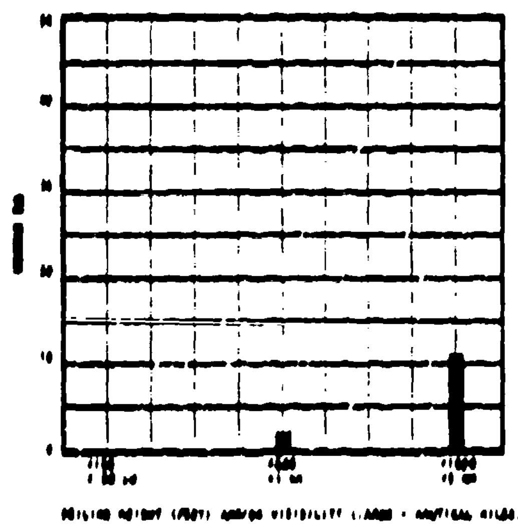


Figure I-3d - Low Visibility and/or Ceiling Height

NOT AVAILABLE

Figure 1-3e - Visibility Persistence

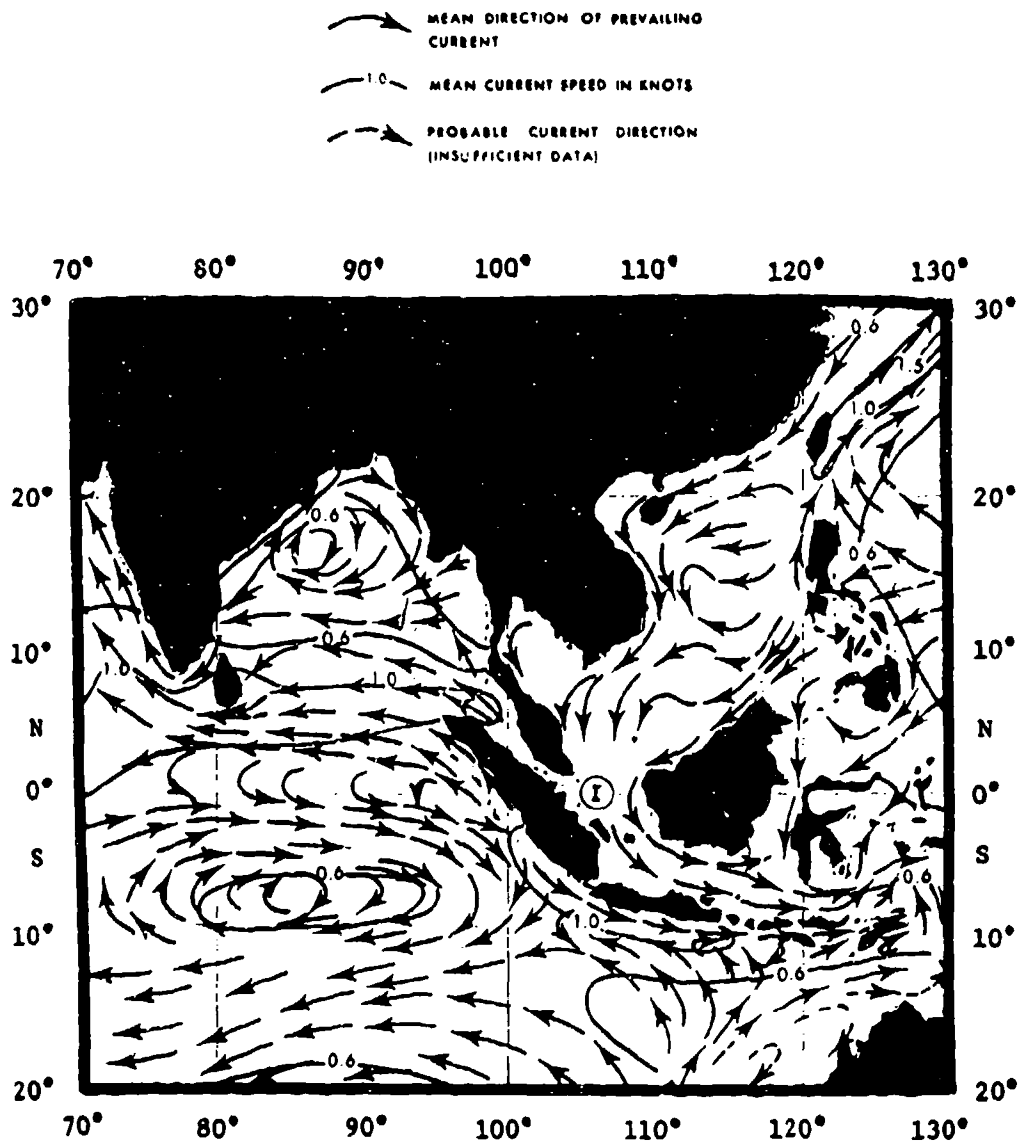


Figure 1-4a - Mean Surface Current Speeds and Prevailing Directions

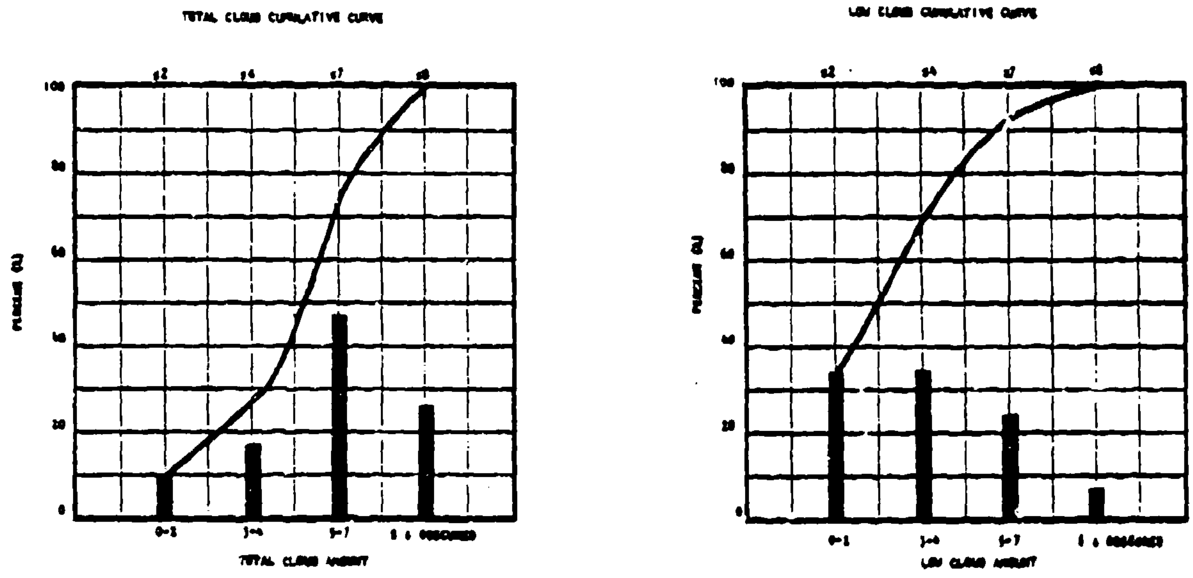


Figure 1-5a - Cloud Amounts - Cumulative Distributions

NOT AVAILABLE

Figure 1-5b - Mean Cloud Amounts

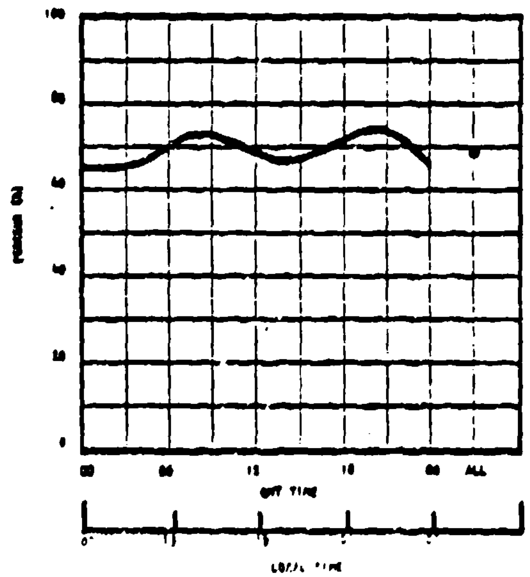


Figure - 1-5c - Good Cloud Conditions - Diurnal Variation

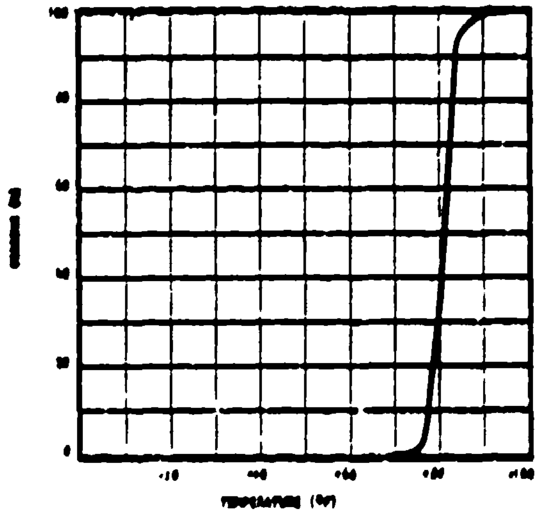


Figure I-6a - Air Temperature - Cumulative Distribution

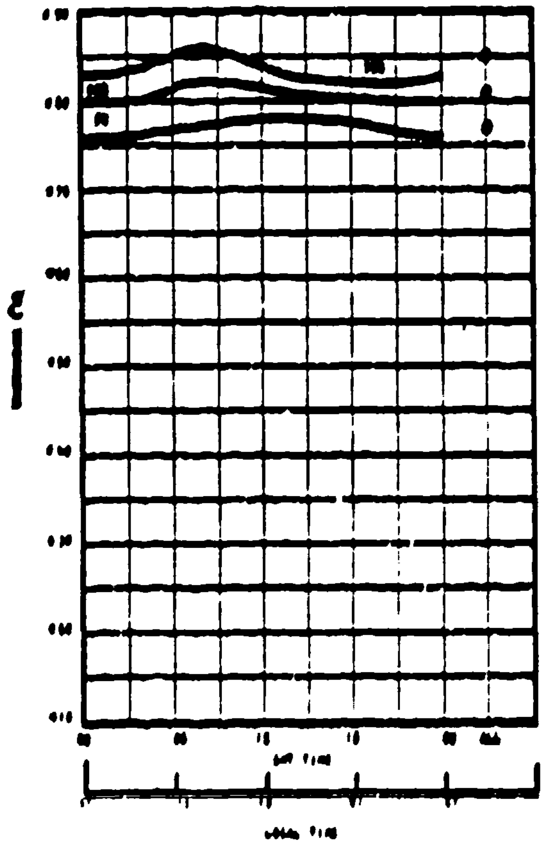


Figure I-6b - Air Temperature - Diurnal Variation

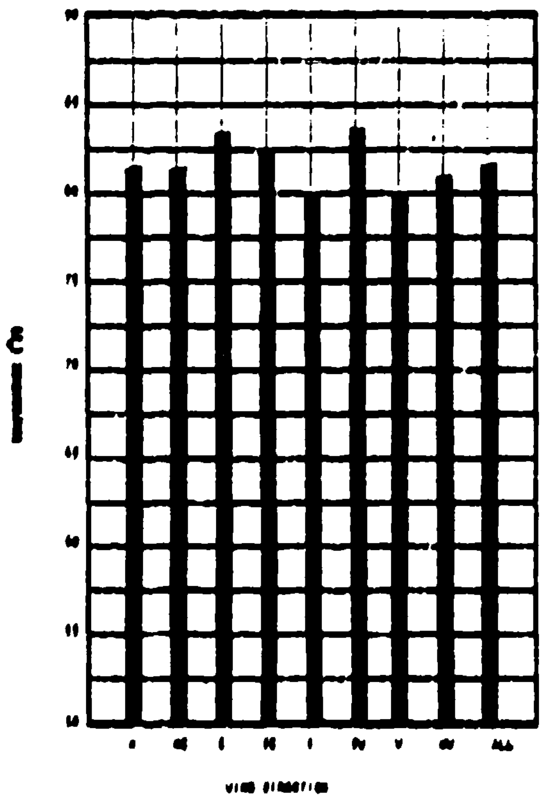


Figure I-6c - Mean Air Temperature by Wind Direction

NO OCCURRENCES REPORTED

Figure 1-6d - Air Temperature and Gales

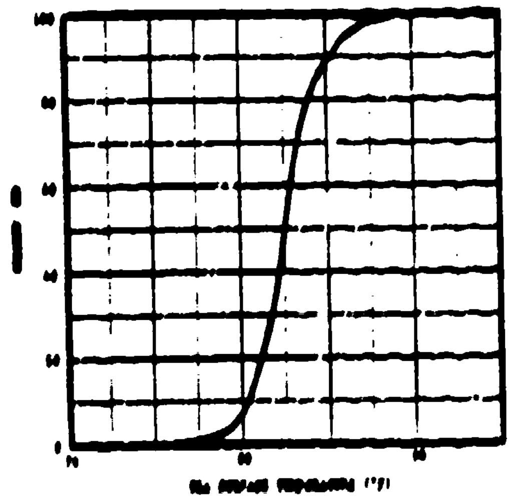


Figure 1-6e - Sea Surface Temperature

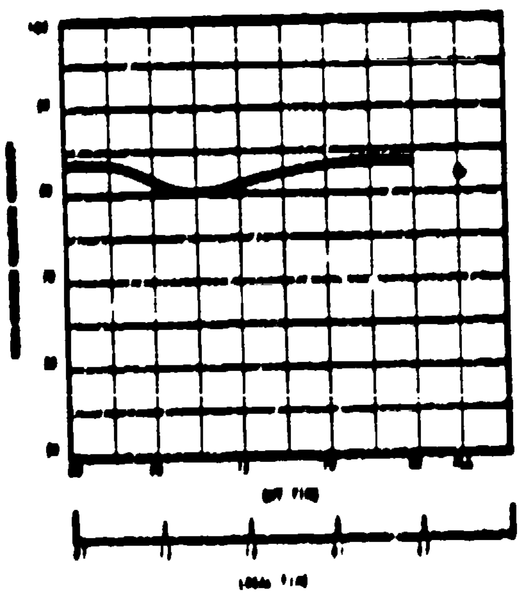


Figure 1-6f - Relative Humidity Diurnal Variation

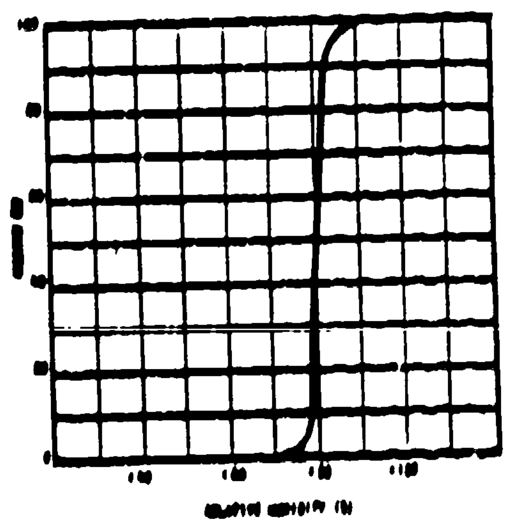


Figure 1-6g - Relative Humidity - Cumulative Distribution

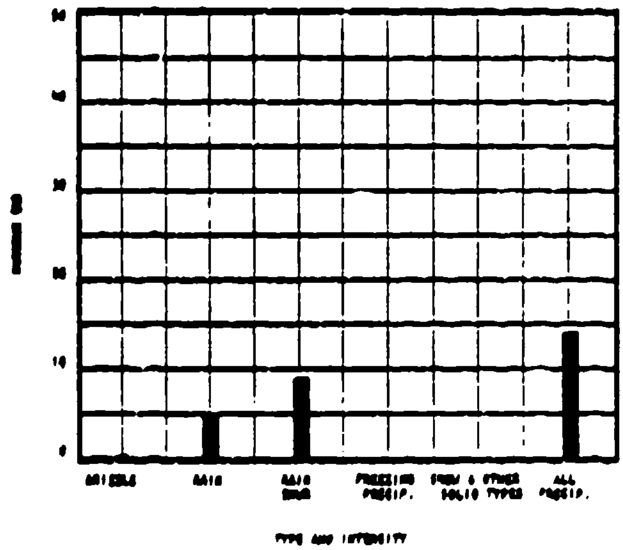


Figure I-7a - Precipitation by Type

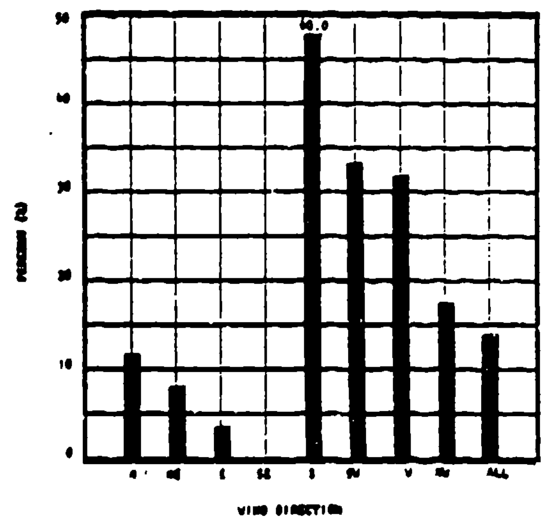


Figure I-7b - Precipitation by Wind Direction

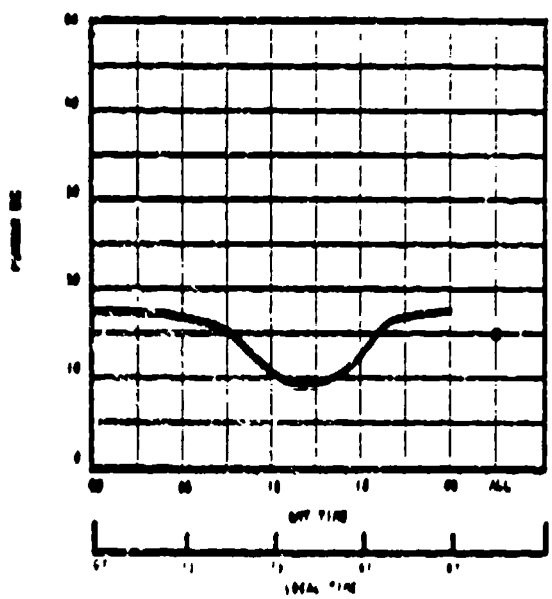


Figure I-7c - Precipitation - Diurnal Variation

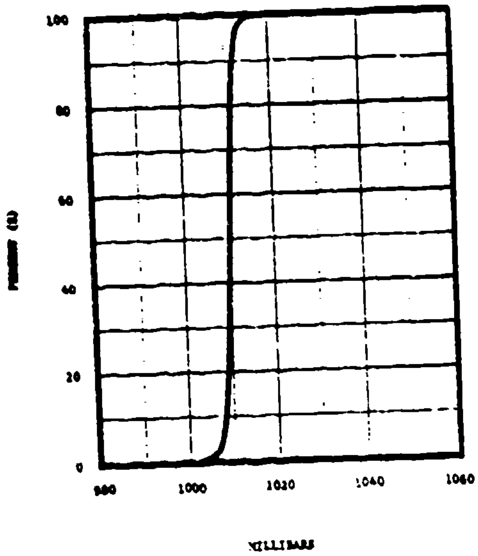


Figure 1-8a - Sea Level Pressure - Cumulative Distribution

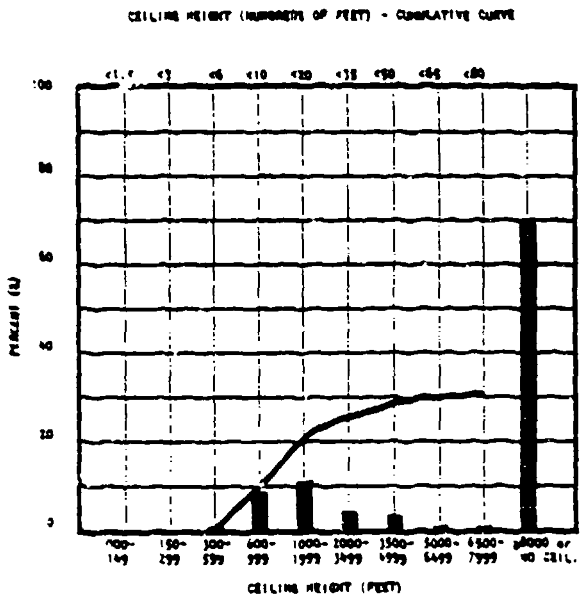


Figure 1-9a - Ceiling Height

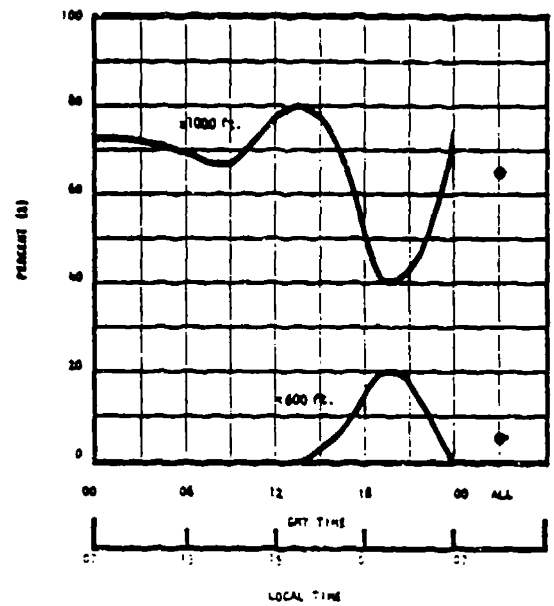


Figure 1-9b - Ceiling Height - Diurnal Variation

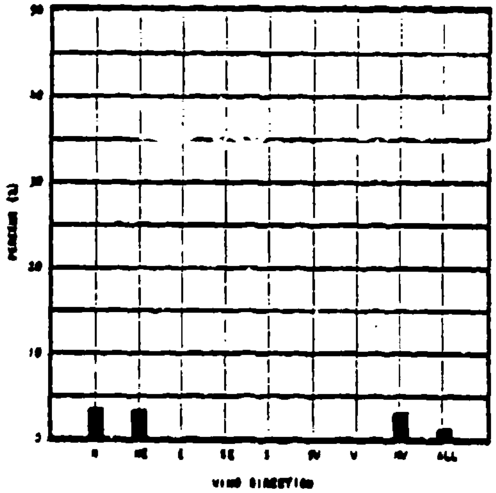


Figure I-10a - Fog versus Wind Direction

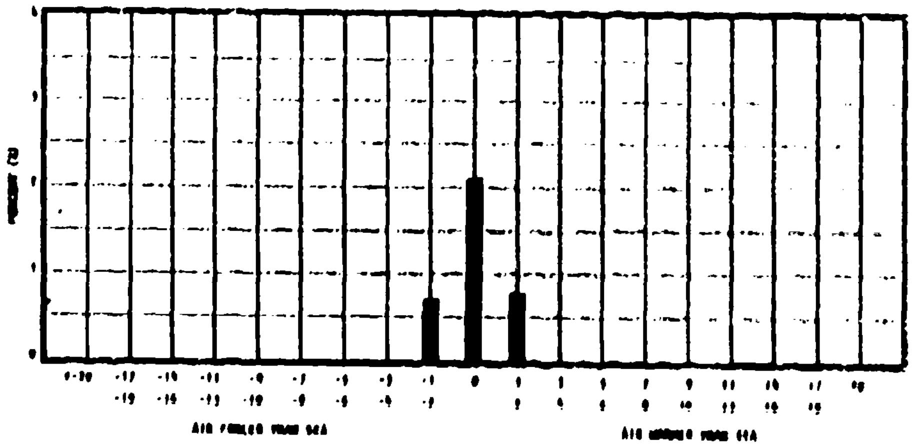


Figure I-10b - Fog versus Air - Sea Temperature Difference

NO OCCURRENCES REPORTED

Figure 1-11a - Low Pressure Centers

NO OCCURRENCES REPORTED

Figure 1-11b - Tropical Cyclones

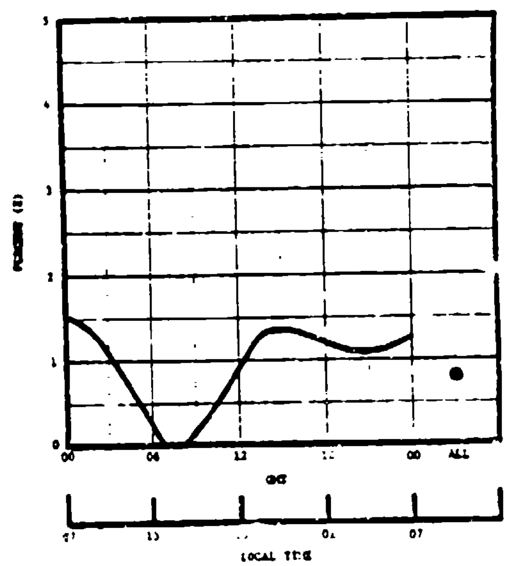


Figure 1-11c - Thunderstorms

NO OCCURRENCES REPORTED

Figure 1-12a - Concentration

Figure 1-12b - Icebergs

Figure 1-13a - Percentage frequency
of moderate and severe potential
for superstructure icing

APPENDIX J

DATA DISTRIBUTION DESCRIPTION

Parts II of each of Appendices A through I contain, where possible, the following natural environment data distributions for their respective oceanographic location.

1. SEA STATE
   a. Sea Height by Wind Direction
   b. Sea Height - Cumulative Distribution
   c. Mean Sea Height by Wind Speed
   d. Swell Height by Direction
   e. Swell Height - Cumulative Distribution
   f. Wave Height and Period
   g. Return Periods for High Waves
2. WIND
   a. Wind Speed by Direction
   b. Return Periods for Maximum Sustained Winds
   c. Wind Direction - Diurnal Variations
   d. Wind Speed - Diurnal Variation
   e. Gale Persistence
3. VISIBILITY
   a. Visibility - Cumulative Distribution
   b. Visibility - Diurnal Variation
   c. Visibility by Wind Direction
   d. Low Visibility and/or Ceiling Height
   e. Visibility Persistence
4. CURRENT
   a. Mean Surface Current Speeds and Prevailing Directions
5. CLOUD COVER
   a. Cloud Amounts - Cumulative Distribution
   b. Mean Cloud Amounts
   c. Good Cloud Conditions - Diurnal Variation
6. TEMPERATURE, HUMIDITY
   a. Air Temperature - Cumulative Distribution
   b. Air Temperature - Diurnal Variation
   c. Mean Air Temperature by Wind Direction
   d. Air Temperature and Gales
   e. Sea Surface Temperature

f. Relative Humidity - Diurnal Variation

g. Relative Humidity - Cumulative Distribution

7. PRECIPITATION

a. Precipitation by Type

b. Precipitation by Wind Direction

c. Precipitation - Diurnal Direction

8. SEA LEVEL PRESSURE

a. Sea Level Pressure - Cumulative Distribution

9. CEILING

a. Ceiling Height

b. Ceiling Height - Diurnal Variation

10. FOG

a. Fog versus Wind Direction

b. Fog versus Air - Sea Temperature Difference

11. STORMS

a. Low Pressure Centers

b. Extratropical (or Tropical) Cyclones

c. Thunderstorms

12. ICE

a. Concentration

b. Icebergs

13. SUPERSTRUCTURE ICING

a. Percentage frequency of moderate and severe potential for superstructure icing.

A description of each of the standard graph types is now given. These descriptions should be referred to in interpreting the data presented in Appendices A through I. Generally, a "standard" format has been adhered to for each environmental parameter at each ocean location. However, due to the multiplicity of data sources, some exceptions do exist. These are clearly annotated as they occur within each Appendix.

1. Sea State

Waves are generally divided into two categories. Sea waves are those which are generated by the local winds. Swell waves are those which have traveled beyond their source region. Significant wave heights, which are the ones generally observed, represent the highest one-third of all waves

present. Occasional extreme waves may reach 1.8 times the significant height. When overall wave summaries are given, the higher of sea or swell is shown; when heights are equal, the longer period is used. Because of the tri-variate nature of the wave observation (direction, period, height) the wave presentations are more complex than most others.

a. Sea height by wind direction offers two presentations in one graph. Because sea direction and wind direction are defined as the same value in the observation, wind direction may also be interpreted as the direction of the sea.

(1) The percentage frequency of observations of seas from different directions is indicated by bar graphs with reference to the bottom and left scales of the chart.

(2) The percentage frequency of waves from specified directions and greater than 2, 6, 9, and 12 feet is shown via plotted numbers within the graph. For example, the number plotted in the cell labeled "S" at the bottom of the graph and "greater than 6" on the right side of the graph gives the percentage frequency of observations having seas from the south with heights greater than 6 feet. These percentages are based on all 100 percent for all directions, not 100 percent for each direction.

b. The cumulative distribution of sea height is shown via a smooth curve with reference to the top and left scales. Bar graphs showing the percentage frequency of observations in various sea height intervals are plotted with reference to the bottom and left scales. All sea (wave) heights given are observed values and can be converted to significant values using Nordenström's relation, described in Reference 1.

$$(\zeta_w)_{1/3} = 1.68\ (\zeta_{obs})^{0.75}\ \text{meters}$$

c. Mean sea heights for various wind speed intervals are shown via bar graphs.

d. Swell height by direction is presented in a manner nearly the same as for the sea described in Section 1b above.

e. Swell heights are displayed in the same manner as the sea heights in b above.

f. Wave heights are presented in two ways in this set of graphs:

(1) A cumulative distribution of wave heights is shown via a smooth curve relative to the top and left scales.

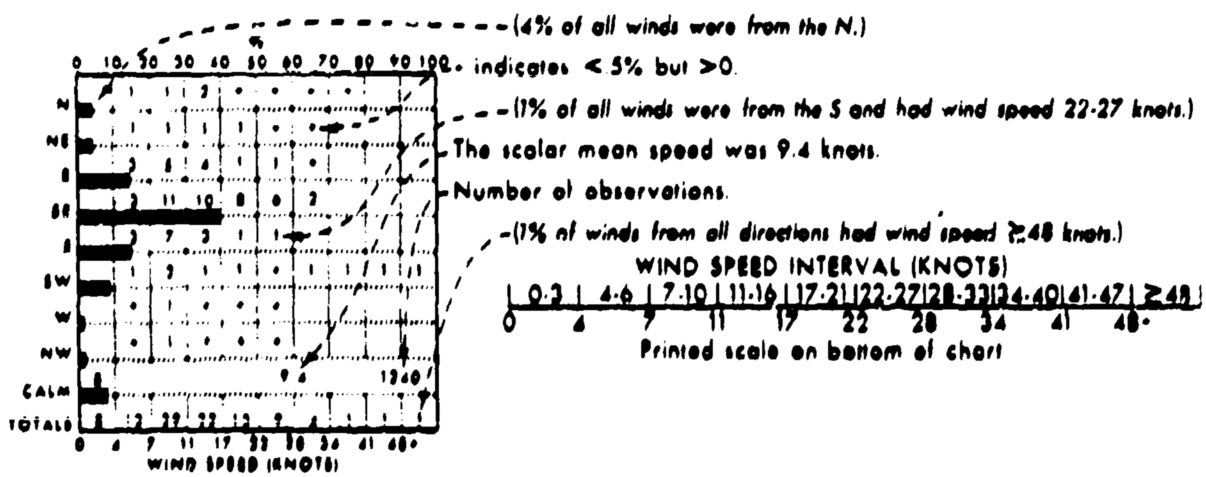
(2) The plotted numbers indicate percentage of observations with various periods (right scale) and heights (bottom scale).

g. Mean return periods (recurrence intervals) for maximum significant and extreme waves are presented in tabular form. For a given return period (say 5 years) the wave value is that height which will be equaled or exceeded, on the average, at least once during the period.

2. Wind

a. Wind speed and direction is portrayed by use of a single graph. (The legend below illustrates use of the graph.)

Direction frequency (top scale): Bars represent percentage frequency of wind observed from each direction. Speed frequency (bottom scale) Printed figures represent percentage frequency of wind speed observed from each direction.

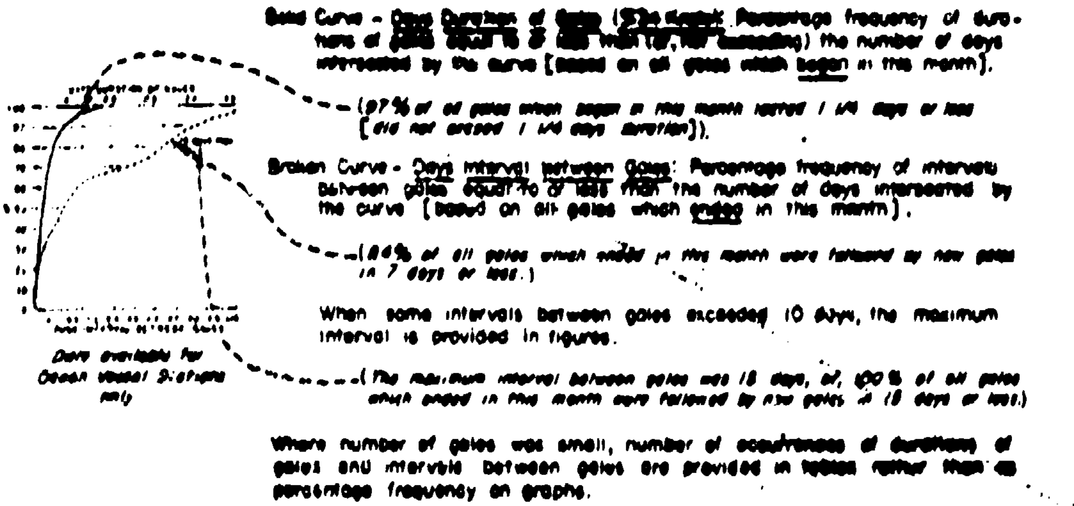


b. Return periods for maximum sustained wind are presented in a manner similar to the waves in Section 1.g.

c. Diurnal variation of wind direction is shown via bar graphs.

d. Diurnal variation of the mean wind speed is shown via a smoothed curve.

e. As in the case of visibility persistence in Section 3.e, continuous observations are needed for gale persistence. Such graphs have been adapted where possible, from the U.S. Navy Marine Climatic Atlas of the World (Reference 3) and are presented in map form.



f. Diurnal variation of wind speed is shown via bar graphs.

3. Visibility

a. The first presentation shows a cumulative curve of visibility observations (top scale) and the distribution of visibilities in certain intervals via bar graphs (bottom scale). The lowest category is read as zero to (but not including) one-half nautical mile.

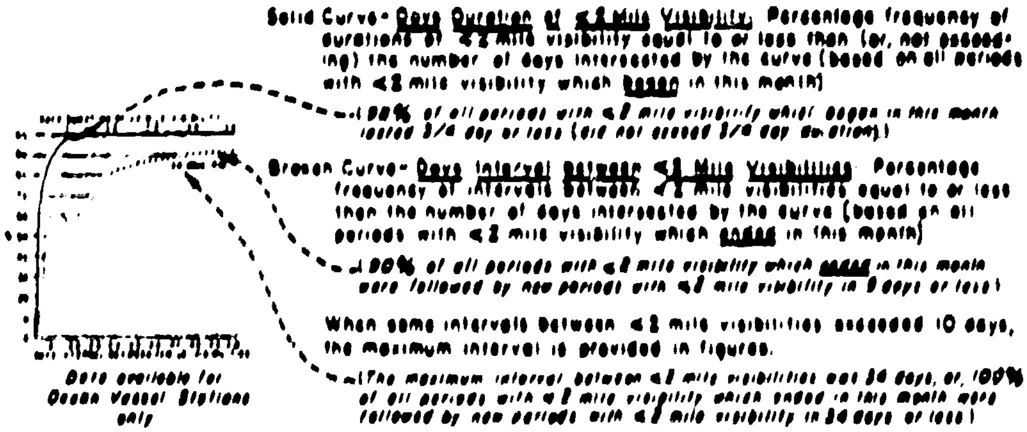
b. The diurnal variation of frequency of observations with visibilities less than one-half, less than 2, and less than 5 nautical miles is shown via smoothed curves. Dots are plotted for the All Hours summary.

c. The percentage frequency of visibilities less than one-half, less than 2, and less than 5 nautical miles is shown versus wind direction via bar graphs. Percentages from each direction are based on 100 percent. That is, if one-fourth of all north winds had visibilities less than 2 nautical miles, then 25 percent will be indicated for the "less than 2" value for north. See Section 2 for wind direction probabilities.

d. Percentage frequency of occurrence of various low visibility and/or low ceiling conditions is depicted via bar graphs. If either visibility

or ceiling or both meet the various criteria then the observation is included in the presentation.

e. Visibility persistence graphs have been adapted from the U.S. Navy Marine Climatic Atlas of the World (Reference 3). Since these summaries are only possible when a continuous series of observations is available, the only graphs presented are for the Ocean Weather Stations near the area of interest:



4. Current

a. A map of surface currents is presented for the worst month for the basin or sea of interest. The map is adapted from the indicated Reference. Tidal currents will predominate in most coastal areas. Currents will also be quite variable during sustained high wind conditions.

5. Cloud Cover

a. Cumulative curves of cloud amount and bar graphs of certain cloud amount increments are presented in the first presentation for both total and low cloud.*

b. Mean cloud amounts are depicted via circular graphs for total and low cloud.*

c. The diurnal variation of good cloud conditions is presented by a smoothed curve. Good cloud conditions are considered to be observations

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*Low cloud is defined as the lowest significant cloud observed and may be a low or middle generic type. It is represented by N_h in the marine synoptic observation.

with low cloud amounts less than 5/8 or, if greater than or equal to 5/8, with bases above 8000 feet.

6. Temperature, Humidity

a. A cumulative curve displays the percentage frequency of occurrence of air temperatures less than or equal to specific values.

b. The diurnal variation of the 5th, 50th, and 95th percentiles of air temperature are shown via smoothed curves. Plotted dots indicate the values for the All Hours summary.

c. Mean air temperature by wind direction is depicted via bar graphs.

d. The occurrence of high winds with cold temperatures is presented on a percentage frequency basis.

e. Sea surface temperatures are summarized by use of a cumulative percentage frequency distribution.

f. Diurnal variation of mean relative humidity is shown by a smooth curve.

g. A cumulative percentage frequency curve is drawn for relative humidities less than certain values.

7. Precipitation

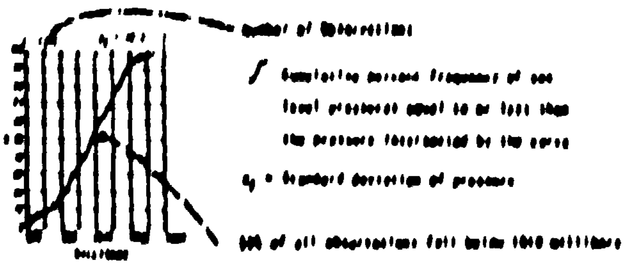
a. Precipitation by type is presented via bar graphs. Coding practices prohibit the separation of moderate and heavy intensities.

b. Precipitation by wind direction is presented by use of bar graphs. Here the percentages are based on 100 percent for each direction. That is, if one-fourth of all north winds were accompanied by precipitation, the bar will indicate 25 percent. See Section 2 for wind direction probabilities.

c. The diurnal variation of precipitation is shown by use of smoothed curves.

8. Sea Level Pressure

a. Cumulative percent frequency, in terms of millibars, is presented in a single graph.



9. Ceiling

This section contains two presentations of the "Low Cloud Ceiling" which is defined as a low cloud amount greater than or equal to 5/8, where low cloud amount is the N_h coded in marine synoptic observations. N_h is the lowest significant cloud amount, which may be a low or middle generic type.

a. The first graph, Ceiling Height, shows the cumulative percentage frequency of observations of ceiling height below certain values. Via bar graphs it also illustrates the percentage frequency of observations of certain ceiling height ranges.

b. The second graph displays the diurnal variation of observations with ceiling below 600 feet, and at or above 1000 feet (which also includes observations with no ceiling).

10. Fog

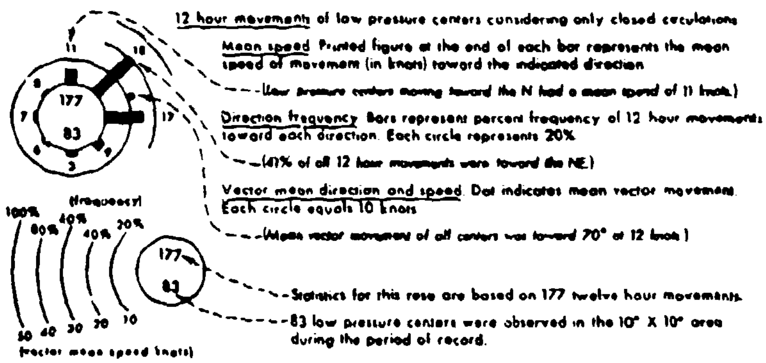
The nature of modern reporting codes makes it impossible to determine the presence of fog when precipitation is occurring.

a. Percentage frequency of fog versus wind direction is depicted by bar graphs. Each direction is summarized on the basis of 100 percent. That is, if half of all north winds were accompanied by fog, then 50 percent will be plotted for north. The average of these percentages will be total fog frequency. See the wind presentation (Section 2) for the probabilities of having winds from various directions.

b. The occurrence of fog versus air-sea temperature difference is also presented using bar graphs. Here the percentages refer to all observations. That is, a bar indicating 2 percent at -9/-10°F means that 2 percent of all observations had an air-sea temperature difference in that range and were accompanied by fog. The plotted number of each air-sea temperature difference category gives the percent of all observations in that category, whether they had fog or not.

11. Storms

a. A map of low pressure center movements and intensities is presented. The data are depicted by rose graphs for 10° latitude-longitude quadrangles.



b. Extratropical (or tropical) cyclone movements and intensities are presented in the same format as low pressure centers. One notable difference in format is the addition of a third number in the center of the rose. This third number gives the probability of having at least one cyclone in the given area (5° latitude-longitude quadrangles) in any given year for the selected month.

c. The diurnal variation of the occurrence of thunderstorms is depicted via a smoothed curve.

12. Ice

Special maps available from the U.S. Navy/Department of Commerce Climatological and Oceanographic Atlas show ice and iceberg conditions.

a. Concentration.

b. Icebergs.

13. Superstructure icing

a. Percentage frequency of moderate and severe potential for superstructure icing is displayed via bar graphs.

Moderate icing potential is derived from observations with temperature less than or equal to 28°F and wind speed greater than or equal to 13 knots. Icing potential is considered severe when temperature is less than or equal to 16°F and wind speed is greater than or equal to 30 knots.

Moderate icing potential relates to a buildup of less than one-tenth of an inch per hour. Severe icing is encountered when buildup is one-tenth of an inch or more per hour.

APPENDIX K

ELECTROMAGNETIC PROPERTIES

The electromagnetic properties reported or derivable herein are taken from Reference 25 and include

a. Upper Air Radio-Refractivity

b. Mean Surface Refractivity, N_s, and Difference at 1 km, ΔN (Above the Surface)

c. Extreme Values of Gradients of Refractivity in Lowest Atmospheric Layer

d. Mean Tropopause Heights

The data presented is in the form of glcbal contours for the months of February, August, and November. As data is not available for all months, the month closest to the worst case month given for each location on Table 3 of the r.in text is used. For example, the electromagnetic data for February should be used for Locations A, B, C, G, and H. August data should be used for Locations E and F. November data should be used for Location D. Reference 13 also contains data for the month of May which has not been included in this report.

The refractivity values reported herein are derived from radiosonde data.

a. Cumulative distributions at 1, 5, 50, 95, and 99 percent levels are given in tabular form for surface refractivity at various world locations. Upper air radio-refractivity is derivable from charts of D_o, the mean sea-level dry term, W_o, the mean sea-level wet term, H_1, the dry-term tropospheric scale height, H_2, the dry-term stratospheric scale height, H_w, the wet-term scale height, and z_t, the mean density tropopause altitude. There parameters are known as the N(z) parameters and are all referenced to sea level. The z_t chart determines which of the dry-term curves should be used. For example, if the desired altitude z, above sea level, of N(z) is <u>below</u> the z_t value specified at the location required, use the tropospheric equation

$$N(z) = D_o \exp\{-\frac{z}{H_1}\} + W_o \exp\{-\frac{z}{H_w}\} \qquad (K1)$$

If the desired altitude is shown the z_t value, use

$$N(z) = D_o \exp\left(-\frac{z_t}{H_1} - \frac{(z - z_t)}{H_2}\right) + W_o \exp\left(-\frac{z}{H_w}\right) \qquad (K2)$$

All three scale heights are required for equation K2, whereas only two, H_1 and H_w, appear in the tropospheric equation. If the surface altitude of the location is greater than 1 km, it is suggested that the "standard atmosphere" value of 3 km be substituted for H_w.

b. Mean surface refractivity N_s is presented in tabular form for various world locations. The monthly mean $\overline{\Delta N}$ (difference between refractivity at the surface and at 1 km above the surface) is presented for the entire world. The $\overline{\Delta N}$ at any specified location is derivable given the monthly mean surface refractivity value, $\overline{N_s}$, and

$$\overline{\Delta N} = b(\overline{N_s} - \overline{\overline{N_s}}) + \overline{\overline{\Delta N}} \qquad (K3)$$

where

$$\overline{\overline{N_s}} = \overline{\overline{N_o}} \exp^{-0.1z} \qquad (K4)$$

and z is the elevation above sea-level in km. World maps of $\overline{\overline{N_o}}$, the yearly sea-level value of refractivity, b, the slope of the regression line of equation K3 and $\overline{\overline{\Delta N}}$, the mean annual value of the refractivity difference between the surface and 1 km. Linear interpolation of the values for these parameters at specified locations is recommended.

c. Initial gradient data obtained for 99 of the 112 world stations in the table presented in part a above are presented in groups of world maps to illustrate various aspects of the percentage distribution of gradients in ground-based layers. The charts presented are

(1) Percent of time gradient $\geq$ 0 (N/km)

(2) Gradient exceeded 10 and 2 percent of the time for 100-m layer

(3) Percent of time gradient $\leq$ -100 (N/km) and percent of super-refractive layers > 100 m thick.

(4) Percent of time gradient $\leq$ 157 (N/km) and percent of ducting layers > 100 m thick.

(5) Percent of time trapping frequency is below 3000 Mc/s, below 1000 Mc/s, and below 300 Mc/s.

(6) Lapse rate of refractivity (N/km) exceeded 25, 10, 5, and 2 percent of the time for 100-m layer.

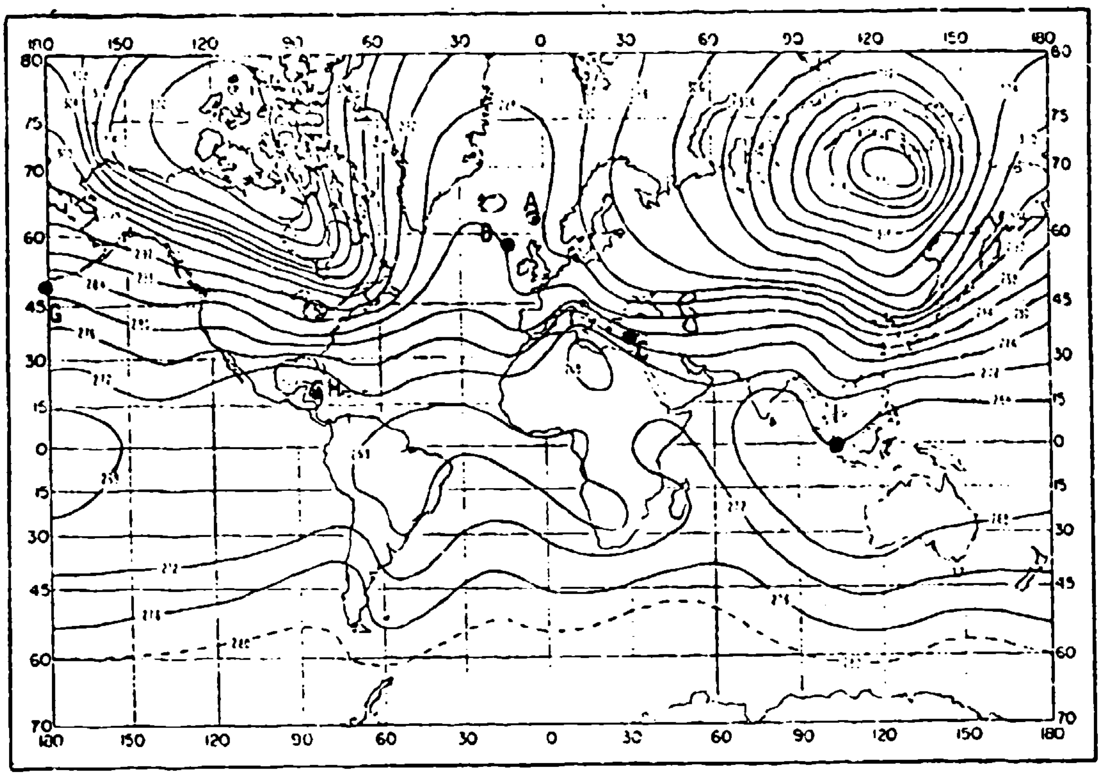
d. Mean tropopause heights obtained in the process of computing N(z) parameters at the 112 stations listed in the table of part a are presented. The heights presented in the world map represent the average of all of the individual altitudes which marked the base of the first layer which had a thickness of at least 2 km and a temperature lapse rate of less than 2°c/km.

Cumulative distribution levels (in percent) of surface refractivity

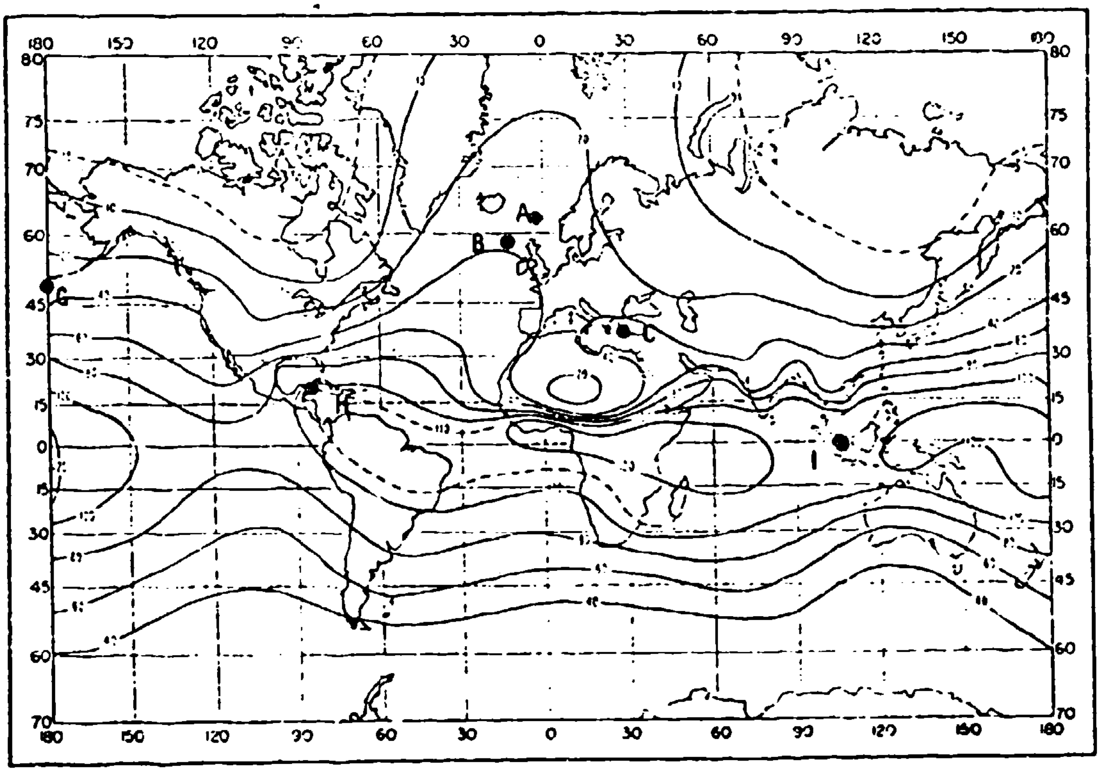
Ident. No.	Station	Elevation (meters)	Latitude	Longitude	February 1	February 5	February 50	February 95	February 99	May 1	May 5	May 50	May 95	May 99	August 1	August 5	August 50	August 95	August 99	November 1	November 5	November 50	November 95	November 99
1.	Abidjan, Ivory Coast	15	05 15N	03 56W	465.0	401.2	390.3	373.0	366.7	397.5	394.2	387.5	377.0	365.1	384.2	381.5	375.2	366.2	361.0	399.2	396.7	388.4	377.9	358.5
2.	Adelaide, Australia	11	34 56S	138 35E	365.9	343.0	314.0	285.7	282.2	349.3	340.2	324.7	307.2	299.6	334.4	330.8	317.8	303.5	295.3	346.1	340.2	310.2	284.9	281.6
3.	Aden, Arabia	4	12 50N	45 01E	391.3	377.9	357.1	336.5	318.5	411.3	397.8	381.9	342.9	308.7	400.6	393.1	366.6	336.5	323.7	381.2	376.3	360.2	335.8	314.1
4.	Amundsen-Scott, Antarctica*	2800	90 00S	00 00	239.6	234.6	226.5	216.8	211.9	262.3	257.0	244.2	233.8	227.3	250.2	256.7	246.0	236.1	231.8	234.6	233.5	227.2	216.9	214.3
5.	Anchorage, Alaska	40	61 10N	149 59W	322.0	317.5	307.2	299.8	293.5	322.5	318.9	308.9	296.2	292.8	339.6	336.3	324.3	308.5	297.3	315.3	314.2	306.6	298.7	295.6
6.	Antofagasta, Chile	187	23 25S	70 28W	357.6	352.8	344.9	334.0	325.2	339.5	338.7	331.8	324.4	322.6	340.2	335.9	328.6	319.8	310.2	342.6	341.5	334.8	325.9	321.4
7.	Aoulef, Algeria	290	26 58N	01 05E	326.4	303.7	284.4	269.2	266.1	296.2	290.2	275.8	268.4	267.4	313.2	302.3	276.9	270.9	270.1	332.2	309.3	288.8	269.8	268.3
8.	Argentia, Newfoundland	17	47 18N	54 00W	329.2	323.8	309.4	300.4	297.7	338.8	329.1	315.8	305.2	299.8	367.1	357.2	337.5	322.6	316.3	343.7	334.7	316.7	306.4	302.2
9.	Ascension Island	79	07 58S	14 24W	378.2	371.6	360.0	347.0	339.1	375.8	370.3	358.4	344.1	335.4	382.5	357.9	346.6	331.0	327.5	368.2	360.9	350.4	338.4	331.2
10.	Athinai, Greece	9	37 54N	23 44E	335.8	330.6	317.6	306.8	290.1	349.6	343.9	331.9	317.7	311.3	364.5	357.5	332.1	313.2	305.5	357.2	351.1	333.4	317.6	313.4
11.	Atlanta, Ga.	309	33 39N	84 25W	348.1	337.3	308.3	294.3	289.4	367.1	360.9	340.1	296.8	289.3	378.8	372.3	357.0	328.3	315.7	349.0	341.5	307.2	292.1	281.1
12.	Bahrain Island	2	26 16N	50 38E	366.1	361.5	338.0	315.3	308.6	409.2	396.7	373.5	341.6	329.6	429.6	423.6	392.5	361.2	359.3	388.7	382.4	357.4	332.1	317.7
13.	Balboa (Albrook), Panama C.Z.	9	08 58N	79 33W	382.3	378.0	367.3	353.7	345.1	393.5	390.2	381.7	369.7	364.3	394.1	391.0	383.0	371.7	365.0	394.5	389.3	381.1	370.1	351.6
14.	Bangui, Central African Republic	385	04 23N	18 34E	371.8	366.3	352.8	319.7	299.1	375.1	369.3	359.6	341.3	338.5	369.3	364.4	359.6	344.6	340.7	374.1	366.0	357.9	339.2	321.0
15.	Barrow, Alaska	4	71 18N	156 47W	351.4	343.0	328.9	314.6	310.7	321.0	318.5	314.5	310.4	308.7	334.0	329.7	318.1	312.0	303.8	334.8	332.2	315.4	307.4	305.6
16.	Beograd, Yugoslavia	243	44 47N	20 32E	325.0	319.2	308.8	297.8	290.1	343.5	337.2	322.7	304.0	295.0	357.4	347.4	328.8	311.1	300.4	329.0	324.9	312.6	303.9	284.1
17.	Bitburg, Germany	366	49 57N	06 34E	308.4	305.2	299.0	288.9	285.3	319.7	318.4	300.9	289.4	286.6	339.0	332.4	318.1	304.8	293.9	362.2	316.0	303.6	296.4	292.2
18.	Bordeaux, France	48	44 51N	00 42W	337.7	332.0	320.9	308.4	304.5	353.7	345.5	332.5	320.0	312.6	366.8	359.8	344.4	332.9	324.8	343.1	334.4	323.6	316.1	313.8
19.	Brownsville, Tex.	6	25 55N	97 28W	375.5	371.6	351.9	314.0	304.4	393.7	389.6	372.4	338.2	325.2	396.4	391.9	381.2	367.6	354.4	382.9	376.8	348.8	312.0	305.6
20.	Calcutta, India	6	22 39N	88 27E	376.8	372.4	343.9	322.3	313.9	420.9	414.0	395.4	366.8	354.4	412.0	406.6	396.3	385.0	378.1	387.9	381.1	367.3	341.4	334.4
21.	Canton Island	3	02 46S	171 43W	385.4	382.2	371.0	361.8	355.9	395.2	391.8	379.5	366.8	363.1	398.1	390.3	375.6	363.7	360.2	388.2	383.9	369.1	358.3	353.8
22.	Caribou, Maine	191	46 52N	68 01W	319.2	313.3	305.7	297.8	294.7	338.1	327.8	307.7	294.8	290.0	364.4	354.0	327.3	310.6	304.6	334.2	319.8	307.7	298.7	296.1
23.	Charleston, S. C.	14	32 54N	80 02W	358.3	352.3	326.4	304.7	299.3	384.5	378.4	356.1	320.6	309.7	397.3	389.7	376.6	351.2	337.2	367.7	359.6	325.9	304.8	298.9
24.	Chatham Island	49	45 58S	176 33W	357.6	356.2	339.6	320.0	317.5	339.8	337.8	324.6	307.1	297.2	335.5	334.6	322.3	310.5	304.0	348.1	345.1	331.9	315.2	313.2
25.	Chita, U.S.S.R.	671	52 05N	113 29E	310.4	307.8	297.3	287.0	282.6	299.4	295.6	281.4	268.2	269.0	335.2	327.9	309.9	289.9	277.8	308.2	304.1	291.6	282.4	279.1
26.	Clark Field, the Philippines	149	15 01N	120 33E	375.3	368.3	348.8	329.7	318.0	391.9	382.1	365.4	343.3	333.1	395.1	387.3	372.8	358.8	347.5	384.1	377.2	360.7	338.2	328.0
27.	Cocoa Beach, Fla.	5	28 14N	80 36W	372.7	367.4	344.2	317.2	309.4	391.2	386.6	367.0	334.1	321.8	402.6	395.7	383.8	367.8	356.7	380.3	373.9	351.7	317.8	311.0
28.	Columbia, Mo.	239	38 58N	92 22W	331.8	319.0	303.8	294.8	290.1	363.2	351.5	325.2	300.4	293.4	375.2	363.3	344.4	317.4	310.6	336.9	327.0	303.4	292.3	285.5
29.	Coppermine, Northwest Territories	9	67 49N	115 15W	345.9	341.8	328.6	319.6	312.9	316.4	316.3	313.5	308.9	306.3	363.8	354.7	327.4	308.6	279.6	338.7	331.3	313.1	306.6	305.4
30.	Coral Harbour, Northwest Territories	59	64 12N	83 22W	341.2	339.8	329.0	311.8	306.6	321.8	317.1	311.1	306.8	304.9	337.2	327.8	316.2	306.8	300.3	326.9	323.8	312.6	304.3	300.1
31.	Curacao Island	8	12 11N	68 58W	381.0	378.8	368.3	359.8	352.5	394.1	390.0	378.0	366.0	361.7	397.7	393.0	382.4	372.4	365.1	391.6	386.8	378.2	368.9	362.9
32.	Dakar, Senegal	22	14 44N	17 30W	367.6	362.5	346.0	319.7	290.0	378.6	373.4	358.4	343.3	335.8	398.2	393.9	381.7	364.8	358.2	388.0	381.8	365.5	339.2	327.5
33.	Darwin, Australia	27	12 26S	130 52E	410.8	402.2	377.6	355.1	329.3	396.9	390.8	359.5	327.0	324.7	380.3	366.3	341.7	285.5	240.8	391.8	388.0	364.8	337.9	333.5
34.	Denver, Colo.	1625	39 46N	104 53W	262.5	259.2	251.8	241.4	235.9	282.4	277.5	260.7	238.8	232.0	304.2	296.9	273.8	250.0	244.1	268.2	262.2	253.1	242.2	240.3
35.	El Paso, Tex.	1194	31 48N	106 24W	290.4	281.8	263.4	250.0	243.4	296.7	288.6	256.2	238.2	232.9	324.7	318.2	294.5	264.8	255.0	289.4	282.6	264.8	253.9	247.4
36.	Ezeiza, Argentina*	20	34 50S	58 32W	379.6	370.4	346.8	325.4	320.4	364.4	354.8	328.7	318.3	284.3	340.2	338.7	323.2	312.7	311.5	364.9	357.4	342.2	320.6	309.7
37.	Fairbanks, Alaska*	138	64 49N	147 52W	342.8	335.3	311.0	294.1	290.9	323.3	318.3	302.2	284.9	280.5	336.5	332.7	319.3	302.1	293.7	314.3	310.8	301.2	294.2	291.7
38.	Ft. Lamy, Chad	300	12 08N	15 02E	332.5	326.8	297.8	280.0	274.8	365.3	361.2	344.9	296.5	281.2	378.2	377.7	369.3	358.8	355.6	368.1	361.4	312.7	285.7	274.3
39.	Ft. Smith, Northwest Territories	203	60 01N	112 00W	352.4	336.4	316.5	301.9	299.3	320.3	315.2	302.9	289.6	285.1	352.0	338.3	320.6	305.3	295.3	322.9	320.5	307.0	300.3	295.9
40.	Ft. Trinquet, Mauritania	359	25 14N	11 37W	324.0	318.8	291.7	270.9	265.8	327.5	317.7	300.2	267.1	265.7	357.4	338.6	296.8	265.8	260.8	332.9	326.3	306.4	272.9	267.5
41.	Gough Island*	40	40 21S	09 53W	357.0	354.5	332.1	320.2	319.0	346.4	346.1	325.8	312.8	310.6	342.6	340.1	324.7	310.1	308.1	349.6	338.5	322.6	311.7	304.3
42.	Guryev, U.S.S.R.	−21	47 07N	51 55E	—	327.4	317.2	297.4	—	350.0	340.9	320.1	298.8	292.2	380.2	365.3	330.5	300.0	299.1	335.9	326.6	318.2	300.2	289.8
43.	Hilo, Hawaii	11	19 44N	155 04W	368.4	365.1	351.6	333.4	329.0	373.2	370.5	358.4	345.0	336.8	383.4	378.9	364.1	348.6	342.3	378.2	374.2	359.0	339.2	332.9
44.	Hong Kong	66	22 18N	114 10E	371.7	367.3	332.7	308.4	295.9	400.7	394.8	378.9	349.8	333.6	402.7	395.1	385.8	370.1	361.1	379.8	369.2	340.5	305.9	298.0
45.	Invercargill, New Zealand	1	46 25S	168 19E	351.7	345.4	327.3	312.4	307.3	337.9	334.0	322.0	310.7	307.4	333.7	329.3	317.9	306.3	301.8	342.0	335.7	322.2	308.9	304.3
46.	Isachsen, N.W.Territories	31	78 47N	103 32W	355.8	348.7	333.3	317.3	310.3	322.4	319.8	313.6	307.9	306.2	326.6	321.9	314.4	307.1	296.0	341.4	336.5	321.5	310.5	306.5
47.	Joliet, Ill.	179	41 30N	88 10W	319.7	316.3	308.4	301.7	299.4	351.5	346.4	319.9	304.4	294.0	391.1	369.6	342.5	319.7	306.5	333.8	322.1	306.8	299.8	297.0
48.	Karaganda, U.S.S.R.	555	49 48N	73 08E	310.1	305.9	296.3	291.5	287.6	315.7	309.8	298.0	276.0	270.8	329.7	324.3	307.7	286.5	277.6	305.7	303.0	297.6	291.4	288.5
49.	Key West, Fla.	3	24 34N	81 47W	382.3	376.5	359.2	324.2	316.7	391.8	387.6	373.9	348.6	335.7	404.9	394.2	382.9	367.4	358.7	391.0	384.7	365.8	337.0	328.7
50.	Khartoum, Sudan	386	15 36N	32 33E	307.2	295.3	284.8	273.4	268.8	345.7	334.9	284.1	264.1	269.3	374.1	369.7	355.6	334.3	298.4	322.4	315.9	299.4	283.8	280.2
51.	Koror, Palau Islands	29	07 20N	134 29E	394.6	392.6	384.6	374.4	368.2	398.1	395.2	388.0	379.4	378.0	396.8	393.7	386.2	378.0	372.8	399.0	395.4	388.3	380.9	377.3
52.	Lae, New Guinea*	12	06 45S	146 59E	408.6	398.3	377.0	355.9	345.4	394.0	392.9	382.3	363.3	359.1	391.1	384.7	376.4	360.8	355.3	416.7	296.2	379.8	364.1	355.5
53.	Lihue, Hawaii	36	21 59N	159 21W	368.0	363.4	351.1	330.8	324.3	368.6	365.5	355.1	337.8	331.8	379.3	375.6	363.6	351.3	347.1	378.8	373.0	360.5	348.1	338.9
54.	Lima, Peru	135	12 06S	77 02W	377.7	364.9	357.7	346.3	341.6	354.6	351.9	344.5	337.5	334.7	342.8	341.3	337.9	331.4	328.2	351.3	348.5	343.0	335.8	330.2
55.	Long Beach, Calif.	20	33 49N	118 09W	342.2	334.4	316.6	296.8	292.3	344.6	340.6	331.0	310.6	295.9	361.3	353.5	343.4	330.7	313.2	349.6	344.7	329.2	304.3	291.8

56.	Laurenco Marques, Portuguese East Africa	44	25 55S	32 34E	391.9	386.1	370.6	352.2	346.4	370.3	363.3	347.0	321.1	315.7	358.4	353.9	336.4	303.6	280.1	386.4	378.4	359.1	342.1	319.7
57.	Luanda, Portuguese West Africa	70	08 49S	13 13E	386.6	381.9	368.3	352.2	342.3	387.6	380.7	364.7	349.1	343.3	361.2	357.6	349.7	336.9	330.8	396.7	393.6	371.6	359.0	351.9
58.	Lvov, U.S.S.R.	329	49 49N	23 57E	315.9	312.6	303.7	294.0	289.6	334.3	331.0	314.6	300.4	297.6	346.9	343.6	329.3	316.0	305.0	325.3	321.4	310.5	302.0	298.4
59.	Macquarie Island	6	54 30S	158 57E	329.0	326.8	315.1	301.3	298.6	328.3	324.7	312.4	298.2	297.2	324.4	322.2	314.3	300.2	294.9	323.3	321.0	310.0	298.5	293.9
60.	Madrid, Spain	601	40 28N	03 34W	315.3	311.2	299.4	284.5	283.0	319.4	316.4	302.7	282.8	282.6	326.5	324.4	291.5	272.5	261.7	309.4	306.1	299.2	290.6	287.1
61.	Majuro Island	3	07 05N	171 23E	390.3	388.0	381.2	367.1	363.3	398.4	394.3	386.6	377.3	371.6	398.1	396.2	385.7	375.3	369.8	400.6	394.9	387.2	378.3	372.7
62.	Marion Island	26	46 53S	37 52E	336.4	332.1	318.5	307.6	306.3	328.0	324.8	313.6	303.3	299.3	329.7	326.8	312.9	303.9	302.1	329.1	324.8	313.3	304.7	300.2
63.	Mazatlan, Mexico	78	23 11N	106 26W	378.1	365.9	351.4	328.2	315.1	386.7	378.3	365.7	352.6	344.3	405.9	400.2	384.7	371.0	367.3	386.2	381.9	364.2	341.6	334.9
64.	Miami, Fla.	4	25 49N	80 17W	376.4	371.1	350.3	319.8	310.2	386.5	383.8	367.0	341.2	330.6	394.2	389.5	377.6	361.1	357.4	378.5	375.0	351.6	322.3	309.1
65.	Midway Island	13	28 13N	177 23W	365.0	361.4	339.9	317.8	313.7	376.9	372.2	361.0	328.0	322.7	389.0	384.3	372.2	357.2	352.5	383.6	379.4	358.8	332.0	324.9
66.	Moosonee, Ontario	10	51 16N	80 39W	335.2	330.5	317.2	306.4	304.5	328.3	320.8	314.6	303.2	298.3	360.8	352.7	331.8	320.4	316.3	331.0	318.9	313.2	306.5	304.8
67.	Moscow, U.S.S.R.	156	55 49N	37 37E	323.2	319.1	306.3	295.5	290.5	336.3	332.6	312.8	295.0	292.3	347.6	342.3	326.8	306.0	297.8	322.9	318.9	309.3	288.4	277.8
68.	Mount Clemens, Mich.*	176	42 36N	86 56W	315.7	311.1	304.2	298.9	297.5	339.0	333.6	311.0	295.6	292.9	371.0	361.6	333.8	311.2	302.8	328.8	323.0	306.7	297.9	293.7
69.	Nairobi, Kenya	1795	01 18S	36 45E	302.2	297.9	285.2	249.1	246.6	310.3	306.7	296.9	271.8	259.5	298.0	294.7	293.8	263.8	254.2	308.1	302.9	293.4	263.5	251.3
70.	Nandi, Fiji Islands	16	17 45S	177 27E	402.7	394.7	383.6	374.0	365.2	383.0	380.4	367.7	349.3	338.7	381.2	376.9	358.9	337.4	329.1	389.2	384.4	371.7	349.3	343.4
71.	Nantucket, Mass.	14	41 15N	70 04W	329.3	326.3	314.9	303.6	300.5	347.9	341.9	328.8	308.2	302.5	382.4	376.0	356.8	329.2	319.4	347.6	342.2	321.0	306.0	300.4
72.	New Delhi, India	216	28 35N	77 12E	329.4	327.3	314.9	301.6	297.2	345.6	342.2	319.1	298.2	280.1	398.7	396.7	385.6	370.8	363.8	354.6	340.4	321.3	310.2	306.0
73.	New York, N.Y.	5	40 39N	73 47W	332.3	324.1	308.8	300.1	295.6	358.9	352.4	323.4	298.8	294.5	385.0	379.8	348.9	316.8	309.9	350.6	339.3	313.5	300.9	295.3
74.	Niamey, Niger*	226	13 29N	02 10E	302.6	301.0	287.4	279.7	279.2	374.8	371.7	352.8	304.5	296.5	384.1	382.4	371.8	362.8	319.8	361.8	356.9	322.3	294.9	290.1
75.	Nicosia, Cyprus	218	35 09N	33 17E	330.2	326.3	312.3	294.4	287.6	348.0	341.9	313.7	280.4	270.4	374.2	365.7	326.9	281.2	267.4	349.1	337.7	314.5	293.9	287.6
76.	Nouvelle Amsterdam Island	28	37 50S	77 34E	374.9	365.4	343.7	317.5	312.8	366.9	353.6	332.6	314.5	306.0	345.0	340.4	327.8	312.7	308.8	351.3	348.8	333.8	313.0	307.0
77.	Odessa, U.S.S.R.	64	46 29N	30 38E	323.4	320.9	314.5	307.1	304.0	384.3	346.9	329.1	312.0	305.3	372.4	367.4	337.2	313.7	307.4	344.4	336.4	321.8	309.9	306.5
78.	Okhotsk, U.S.S.R.	7	59 22N	143 12E	329.6	326.9	315.3	306.4	298.8	322.4	320.6	313.7	298.5	295.4	347.9	345.6	336.1	314.3	298.9	322.2	319.5	311.6	302.3	296.6
79.	Ostersund, Sweden	309	63 11N	14 37E	310.8	308.8	299.7	291.7	288.3	322.1	314.2	303.7	293.8	289.5	335.2	328.3	316.7	304.3	299.9	312.1	310.0	302.9	294.7	293.7
80.	Perth, Australia	60	31 57S	115 49E	362.0	344.8	316.4	288.7	281.5	360.3	345.5	321.1	298.5	290.4	345.6	338.9	320.5	301.6	294.6	350.4	337.3	315.8	289.2	283.4
81.	Pittsburgh, Pa.*	361	40 30N	80 13W	314.4	311.8	298.7	284.8	279.5	339.8	335.8	309.2	286.7	281.2	358.4	354.6	333.4	306.2	302.7	—	317.0	300.0	292.2	—
82.	Port Lyautey, Morocco	12	34 18N	06 36W	349.6	343.6	328.5	306.7	295.4	363.1	357.0	338.9	315.8	290.7	376.4	372.4	356.3	329.9	318.8	356.4	353.5	337.9	313.2	308.5
83.	Puerto Montt, Chile	6	41 29S	72 51W	354.7	349.5	335.6	321.8	315.6	345.5	339.2	326.6	317.4	311.6	335.6	331.9	323.6	316.6	310.9	343.6	340.5	330.2	319.7	315.0
84.	Raoul Island	49	29 15S	177 55W	382.7	377.9	352.0	316.2	324.1	372.1	367.3	343.2	323.3	319.8	360.5	355.1	331.5	313.2	309.4	365.2	362.0	342.0	323.9	317.8
85.	Recife, Brazil	10	08 07S	34 55W	396.6	389.4	378.1	350.6	345.4	393.3	392.2	376.8	358.7	343.9	392.5	383.5	366.8	349.1	343.6	391.1	384.2	363.4	342.7	329.3
86.	Sable Island, Nova Scotia	3	46 56N	60 02W	325.3	321.3	312.0	305.6	301.9	396.6	383.2	324.5	315.9	311.8	371.4	365.8	361.1	336.2	327.1	345.5	329.9	319.8	309.0	304.9
87.	Saigon, Viet Nam	10	10 49N	106 40E	385.5	383.2	367.6	343.6	330.7	403.6	399.1	390.8	380.4	375.1	399.1	396.5	387.9	378.1	371.8	395.7	391.1	379.8	356.3	342.1
88.	San Diego, Calif.	9	32 44N	117 10W	343.5	339.5	326.9	307.2	293.5	346.1	342.3	332.7	315.8	295.4	364.0	350.1	348.3	335.4	330.0	350.0	346.2	327.5	298.6	292.7
89.	San Juan, P. R.	19	18 26N	66 00W	373.6	371.0	350.0	340.7	334.1	387.5	384.1	374.2	357.4	347.9	394.1	390.0	379.0	364.7	350.8	390.4	386.0	372.6	355.2	348.8
90.	Seattle, Wash.	15	47 41N	122 16W	330.2	327.1	317.9	306.2	300.7	341.1	333.2	322.2	306.3	299.8	348.1	343.9	333.9	320.0	314.4	336.2	332.4	323.6	312.9	306.2
91.	Shemya, Alaska	37	52 43N	174 06E	320.7	316.2	306.2	298.4	296.9	322.2	319.2	311.4	302.9	299.8	343.5	336.9	326.3	315.8	307.6	332.7	318.0	306.2	297.4	294.2
92.	Singapore	18	01 21N	103 54E	390.0	385.4	378.5	369.0	367.0	401.0	396.5	388.4	376.8	330.0	393.5	392.9	386.6	376.2	330.6	391.7	388.8	382.4	374.2	364.5
93.	Stanley, Falkland Islands	53	51 42S	57 52W	334.7	331.8	318.0	303.8	299.3	328.1	324.4	314.9	306.8	302.6	321.5	320.5	314.0	305.3	303.0	331.5	324.8	315.8	301.6	295.5
94.	Swan Island	10	17 24N	83 56W	390.4	378.0	368.4	341.8	333.4	396.3	390.8	380.0	353.4	340.7	384.9	393.0	380.7	379.4	377.4	395.2	391.9	379.5	351.0	342.0
95.	Syktyvkar, U.S.S.R.*	96	61 40N	50 51E	328.5	318.6	308.0	300.6	298.0	328.0	321.4	309.5	295.3	292.4	358.3	348.9	324.8	306.6	305.2	328.7	320.7	313.3	303.6	301.5
96.	Tananarive, Malagasy Republic*	1310	18 54S	47 32E	362.3	325.0	318.3	300.4	250.7	328.1	312.8	302.5	294.4	290.6	311.8	307.9	298.2	292.1	276.2	320.2	317.9	311.0	302.0	299.6
97.	Tashkent, U.S.S.R.	428	41 16N	69 16E	310.9	306.6	296.9	280.0	276.4	331.8	321.6	306.4	289.8	283.9	327.4	315.9	300.9	290.0	290.1	312.7	309.7	299.9	279.4	276.0
98.	Tateno, Japan	27	36 03N	140 08E	326.9	322.8	313.0	300.0	295.2	371.4	364.2	341.7	313.7	306.6	397.4	394.2	380.7	356.2	351.8	350.1	344.0	324.1	310.9	303.5
99.	Tatoosh Island, Wash.	26	48 23N	124 44W	331.9	328.2	318.9	304.3	299.8	336.0	333.9	326.4	317.0	311.1	348.2	344.5	337.9	331.2	329.2	340.9	335.5	322.7	307.9	303.0
100.	Townsville, Australia	4	19 16S	146 45E	400.3	391.3	365.6	332.2	329.4	378.6	370.6	343.2	313.6	295.4	362.6	356.9	333.0	306.7	285.6	383.0	376.4	334.6	318.3	291.7
101.	Tripoli, Libya	10	32 54N	13 17E	339.6	336.3	321.0	295.7	285.1	367.9	361.3	342.3	307.4	294.4	395.8	387.1	364.2	330.9	311.0	364.2	351.6	329.2	306.0	290.9
102.	Tura, U.S.S.R.*	147	64 16N	100 14E	356.2	348.6	324.9	305.2	301.4	316.2	310.6	300.8	290.3	284.5	343.4	336.7	318.4	294.6	292.8	343.3	338.7	319.2	304.6	301.6
103.	Verkhoyansk, U.S.S.R.*	136	67 33N	133 23E	366.2	350.2	342.4	322.5	314.9	311.8	309.8	300.2	289.8	287.3	340.3	335.0	313.5	303.0	297.8	352.9	351.7	334.3	314.8	307.9
104.	Vladivostok, U.S.S.R.	188	43 07N	131 54E	317.2	313.8	300.1	303.4	294.4	334.3	330.1	316.8	298.1	291.3	376.9	371.3	353.4	330.4	314.4	322.9	321.1	304.0	300.1	295.2
105.	Wake Island	4	19 17N	166 39E	383.6	377.2	360.9	338.9	330.0	387.5	384.0	373.6	354.1	344.2	395.3	391.6	382.1	370.6	364.0	393.3	388.9	376.5	361.1	355.3
A.	Ship A*	‡	62 00N	33 00W	328.8	325.9	307.0	293.9	292.1	330.0	327.0	318.6	309.7	292.7	335.8	333.4	324.9	313.5	276.7	330.0	326.8	309.5	297.9	294.2
C.	Ship C	‡	52 45N	35 30W	332.3	329.9	312.9	302.9	298.8	339.7	335.3	320.8	308.6	305.9	356.2	348.9	332.0	318.6	316.3	338.3	335.7	318.5	304.8	302.1
D.	Ship D	‡	44 00N	41 00W	349.8	344.9	318.9	306.5	303.7	358.2	355.4	329.8	312.1	308.3	383.2	378.0	358.5	331.8	323.7	362.1	355.4	327.6	311.3	308.6
J.	Ship J	‡	52 30N	20 00W	337.2	332.9	317.5	301.7	297.6	340.8	339.3	321.5	312.7	308.8	350.5	357.7	345.3	324.1	318.6	346.1	344.3	331.2	315.0	292.9
K.	Ship K	‡	45 00N	16 00W	343.4	340.6	325.1	311.1	308.8	352.0	350.3	336.5	319.2	314.6	371.5	366.7	349.5	330.1	325.3	351.9	347.0	331.3	318.9	310.4
M.	Ship M	‡	66 00N	02 00E	323.6	321.1	311.7	304.9	302.8	333.8	330.9	319.8	307.7	304.5	341.9	338.4	327.6	313.6	310.4	330.0	327.0	318.4	303.7	297.9
V.	Ship V	‡	34 00N	164 00E	366.4	360.8	333.6	311.0	306.6	374.5	370.8	351.7	322.9	317.0	393.0	390.9	378.4	351.3	338.5	379.0	376.1	344.8	323.1	318.5

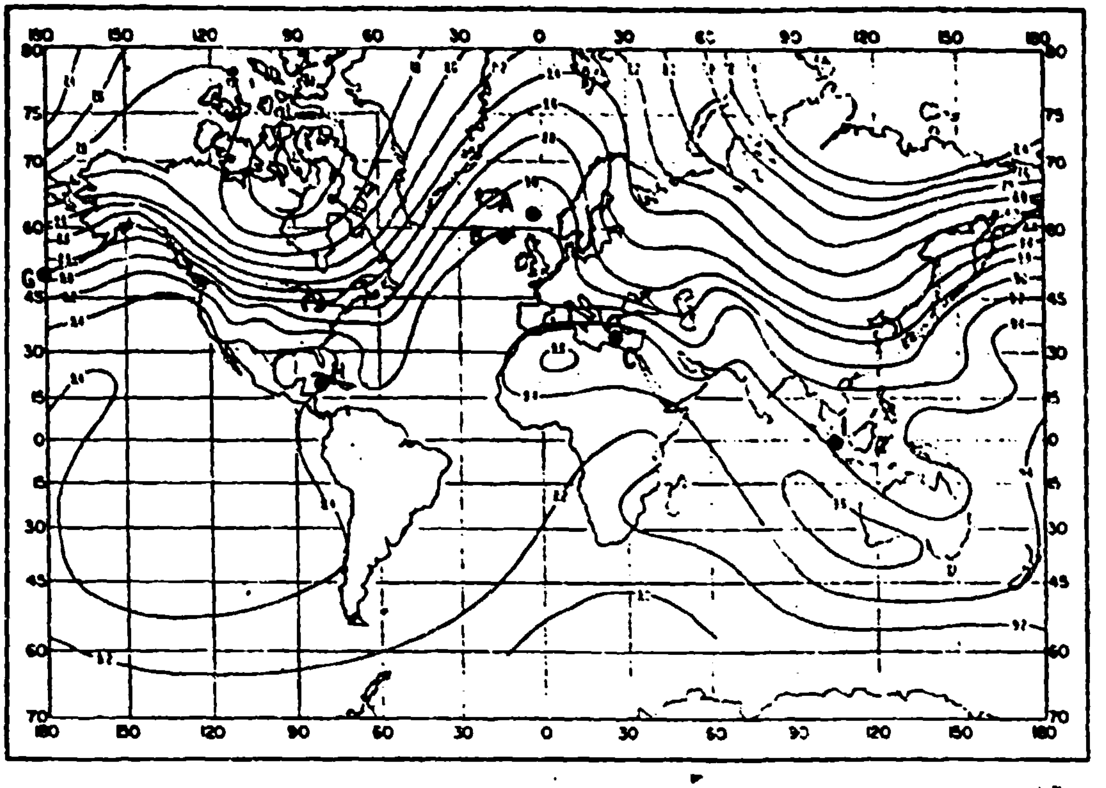
*Less than 2 years of data.
‡ No elevation given.



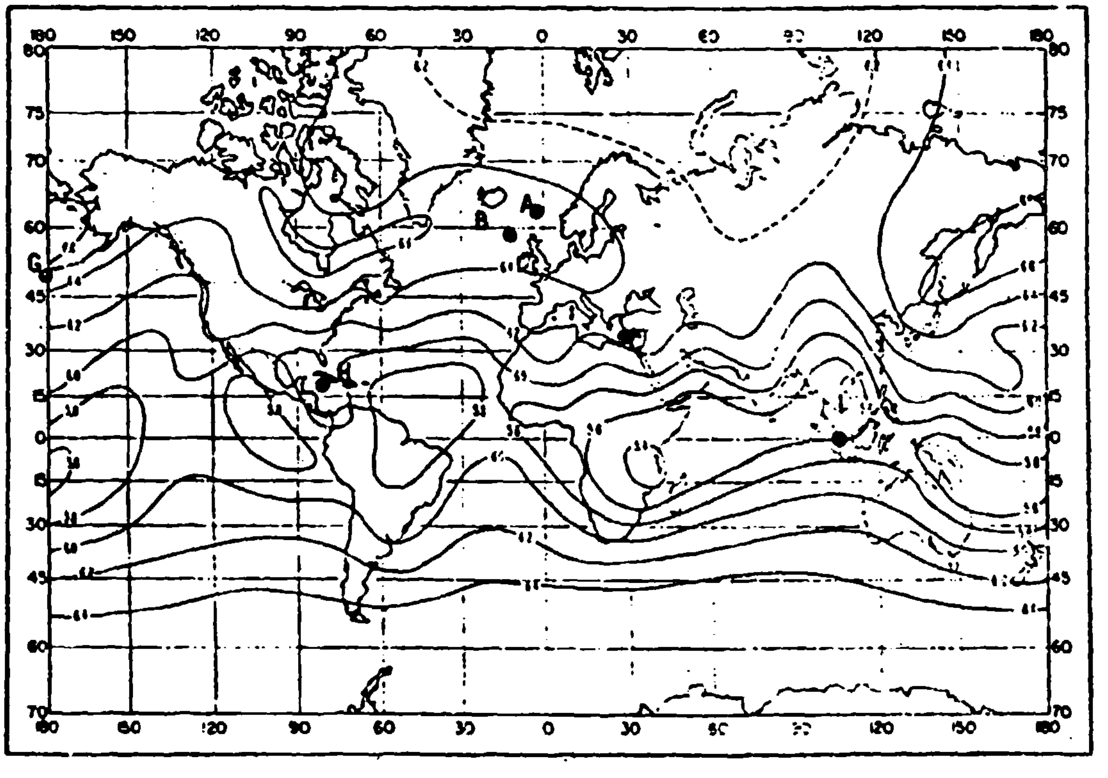
Mean sea-level dry term, D_0: February.



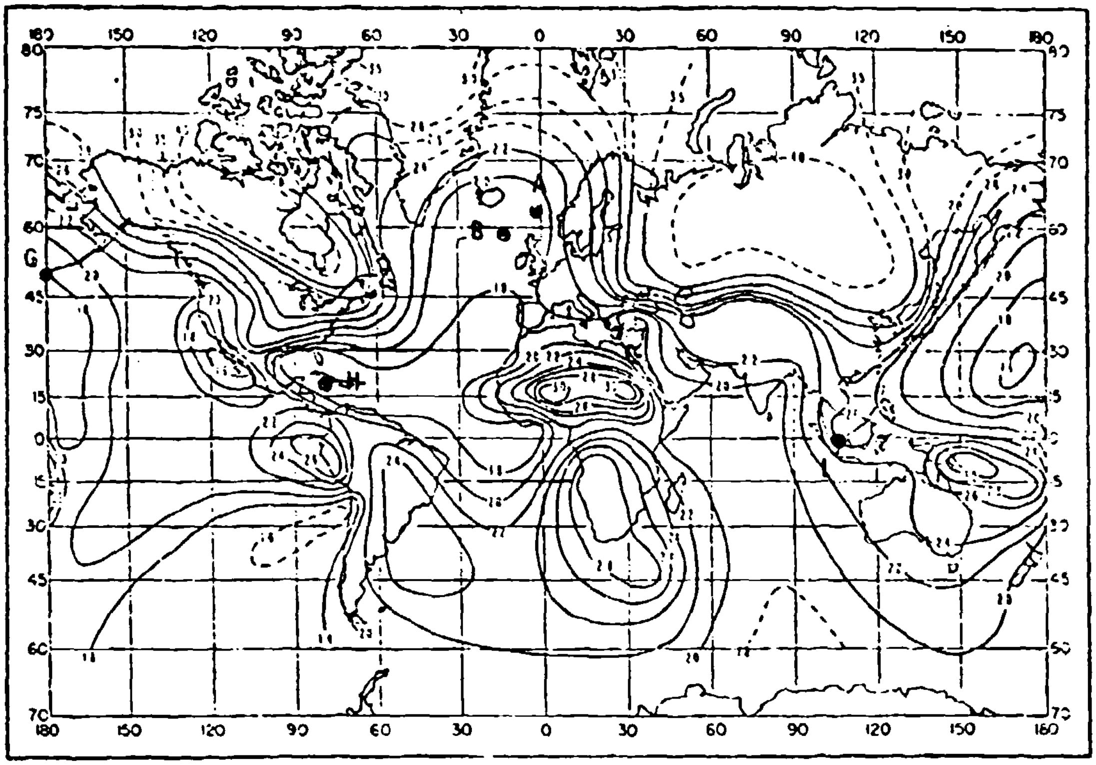
Mean sea-level wet term, W_0: February.



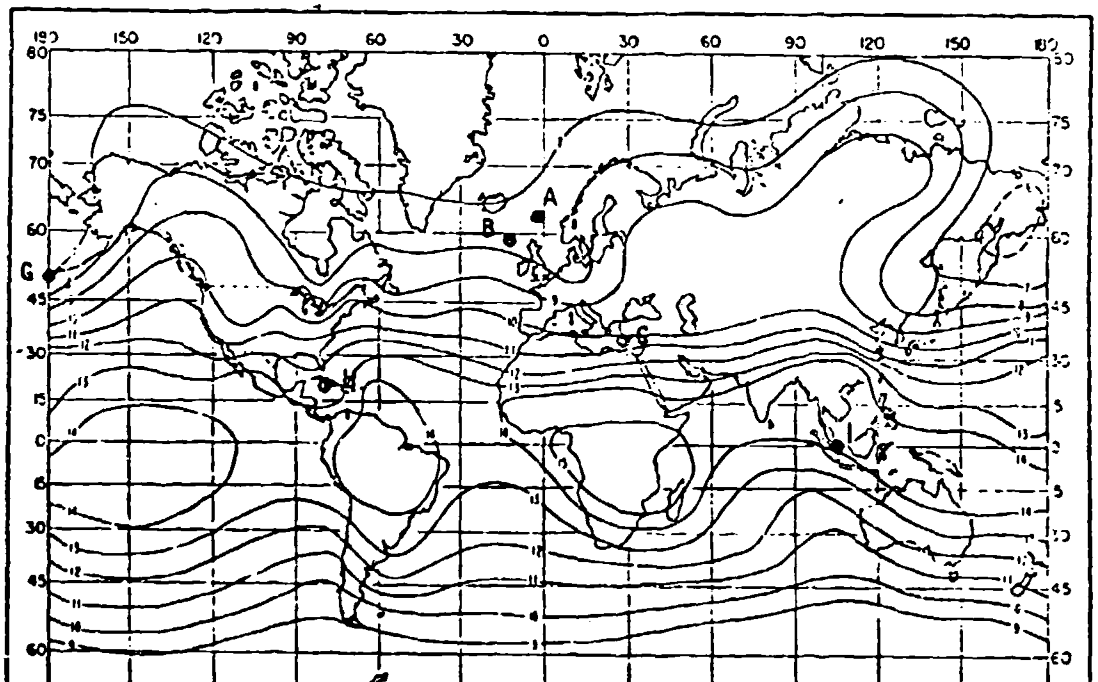
Dry-term tropospheric scale height in km, H_1: February.



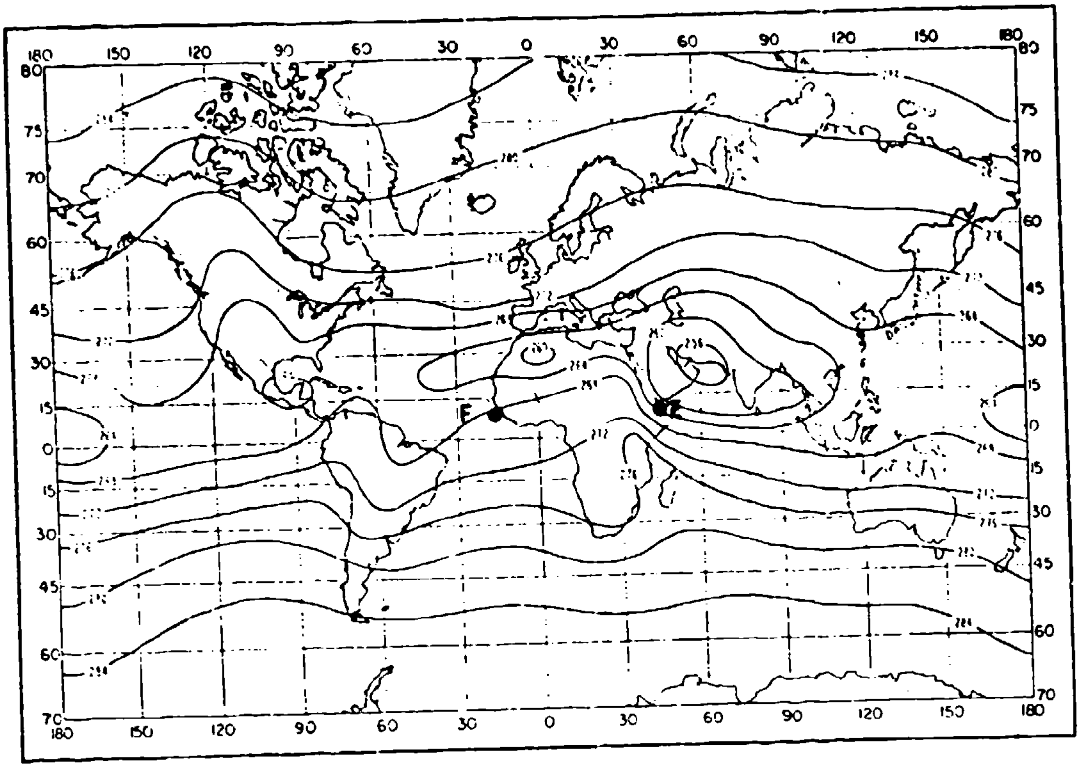
Dry-term stratospheric scale height in km, H_2: February.



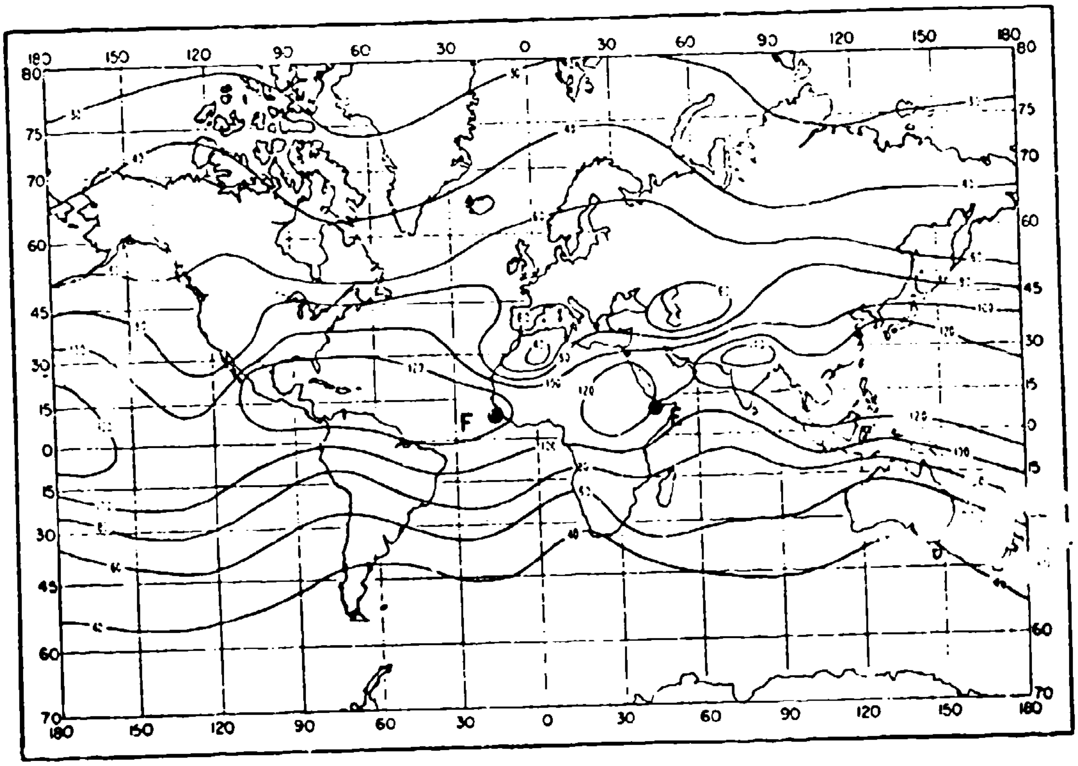
Wet-term scale height in km, H_w: February.



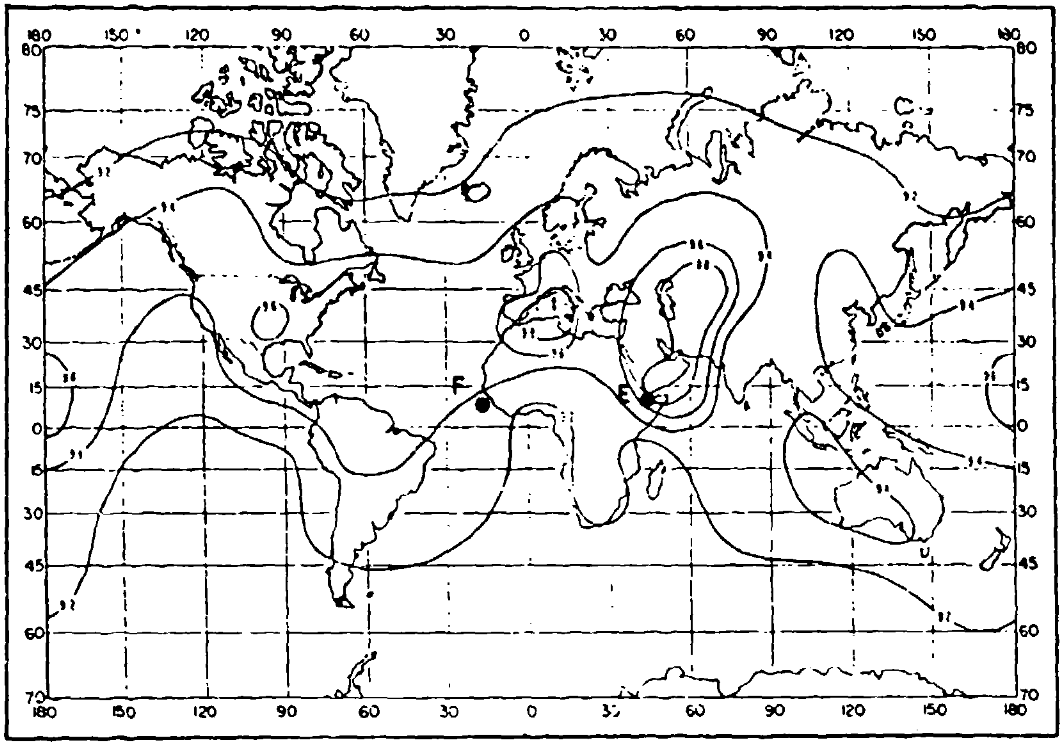
Mean density tropopause altitude in km, z_t: February.



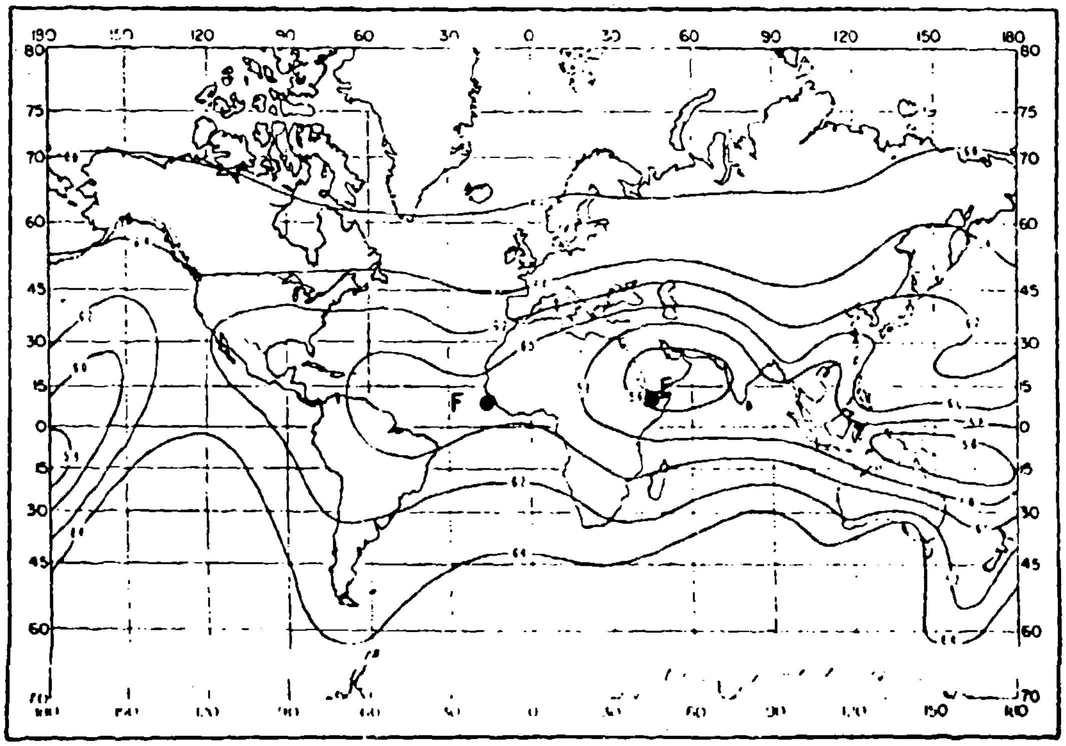
Mean sea-level dry term, D_o: August.



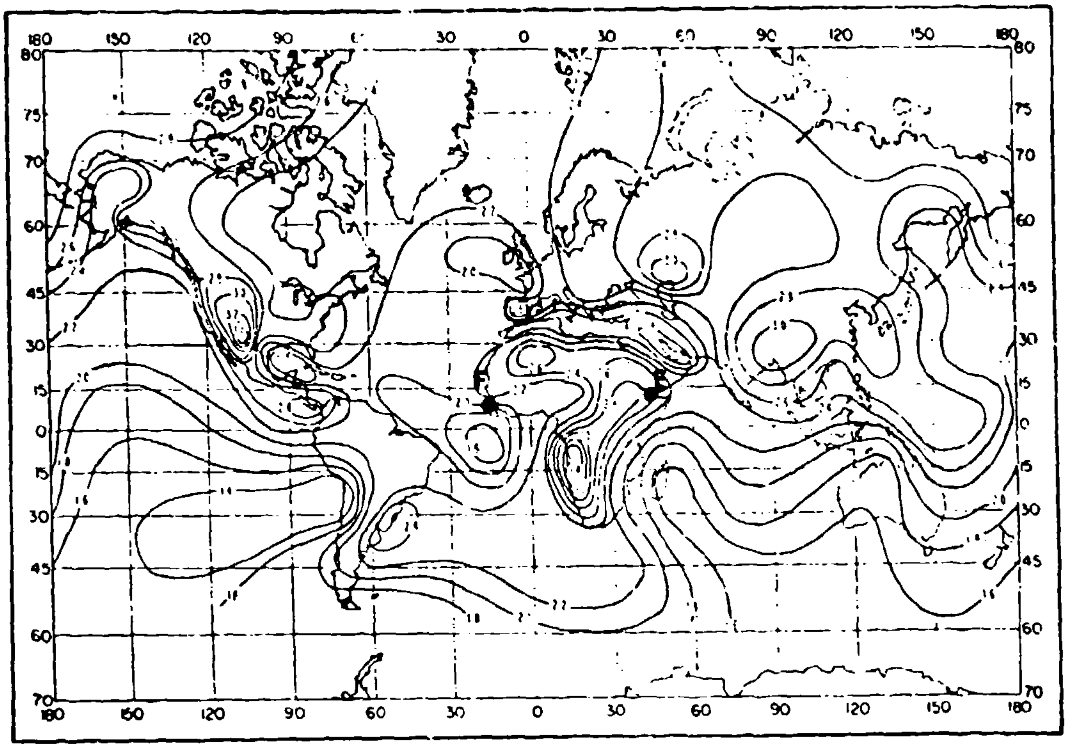
Mean sea-level wet term, W_o: August.



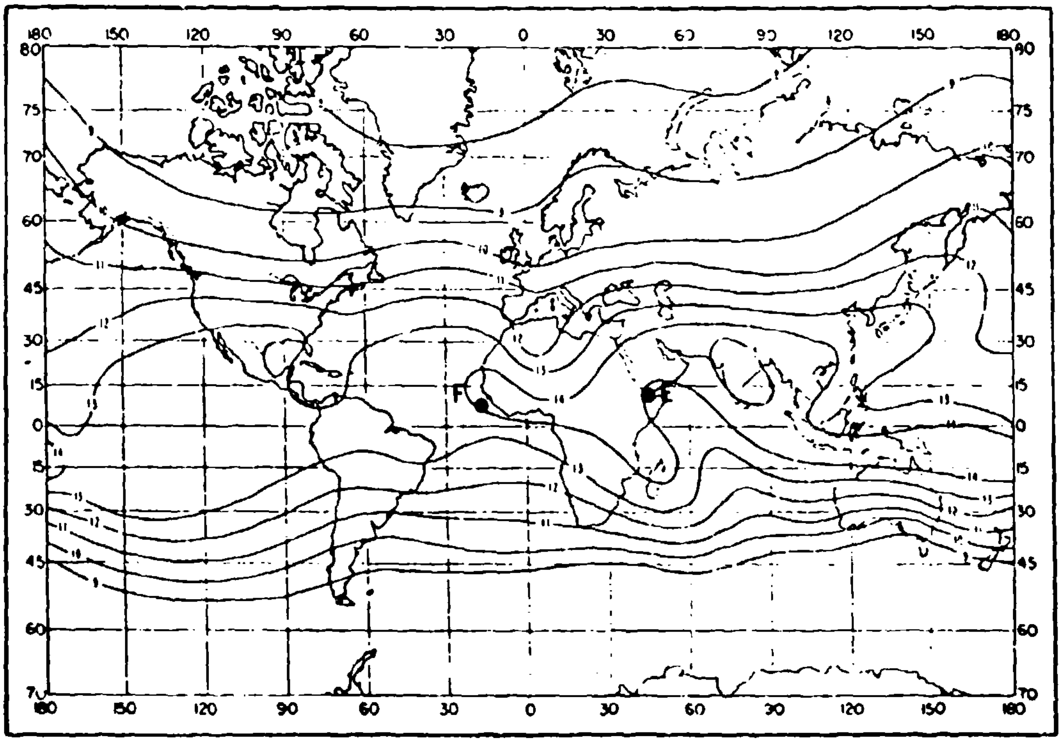
Dry-term tropospheric scale height in km, H_1: August



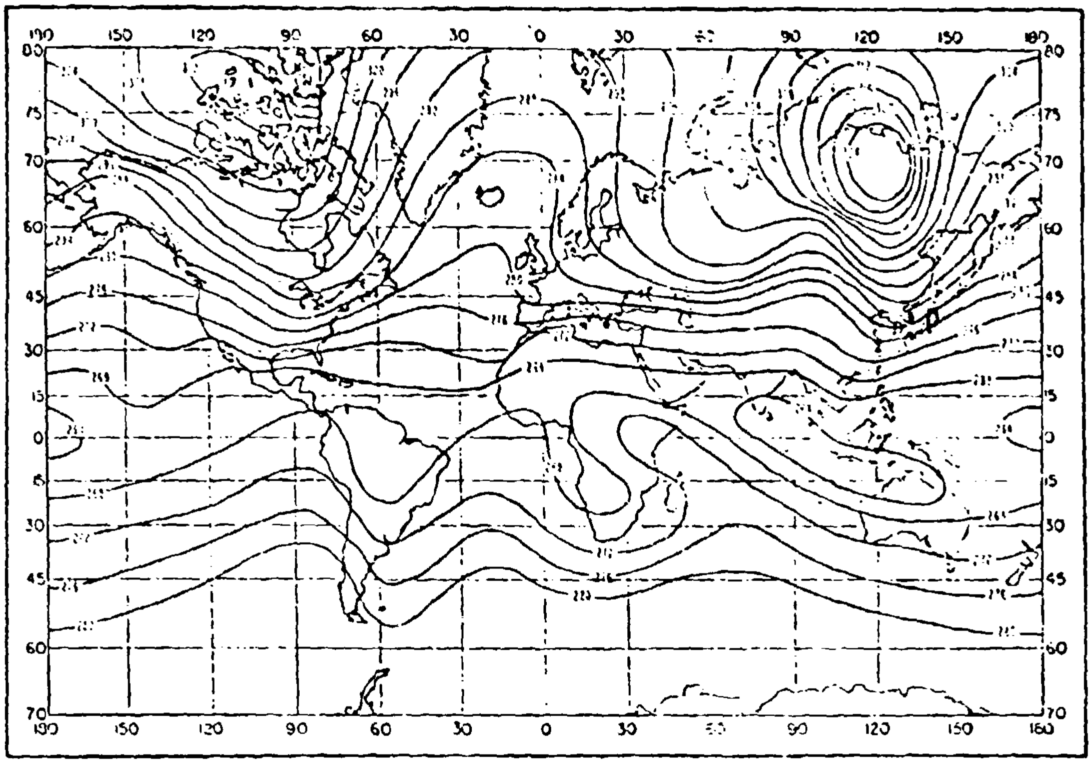
Dry-term stratospheric scale height in km, H_2: August.



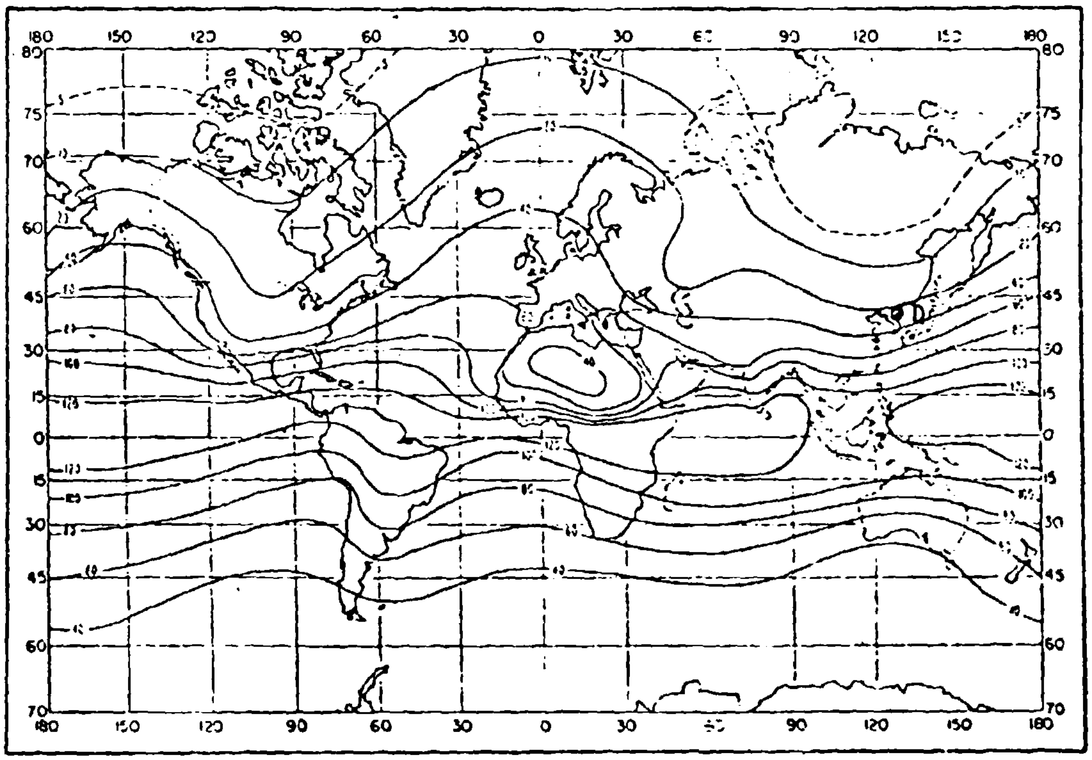
Wet-term scale height in km, H_w: August.



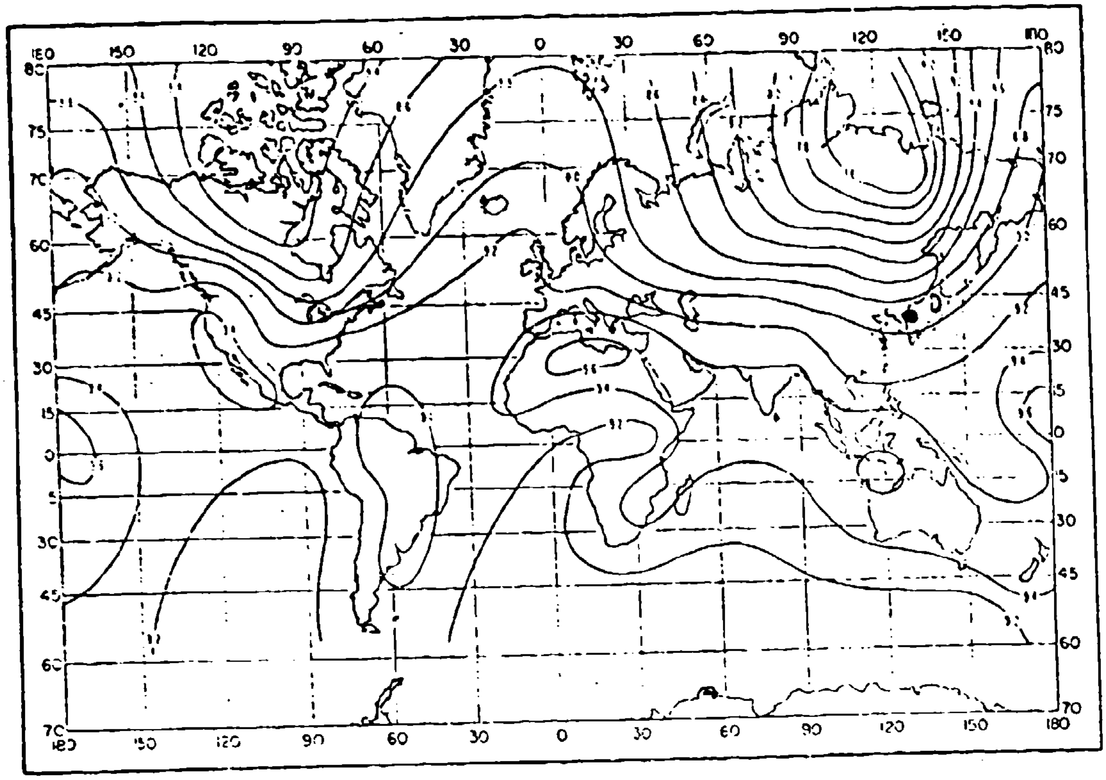
Mean density tropopause altitude in km, z_t: August.



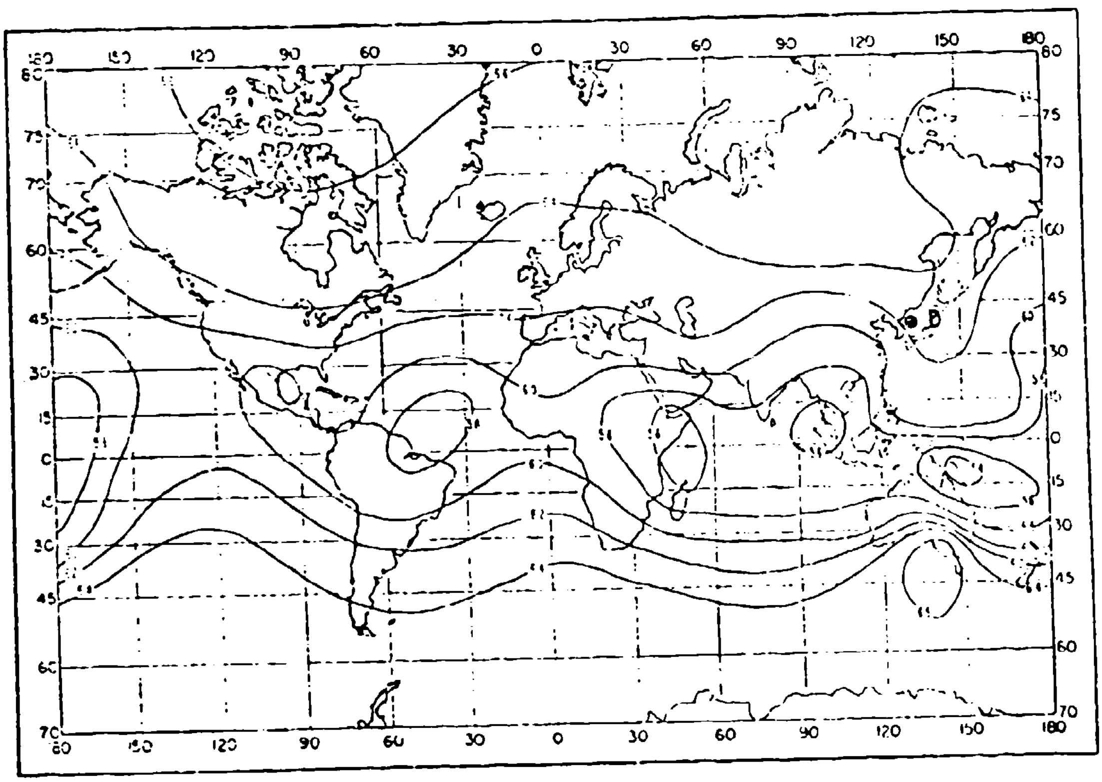
Mean sea-level dry term, D_2: November.



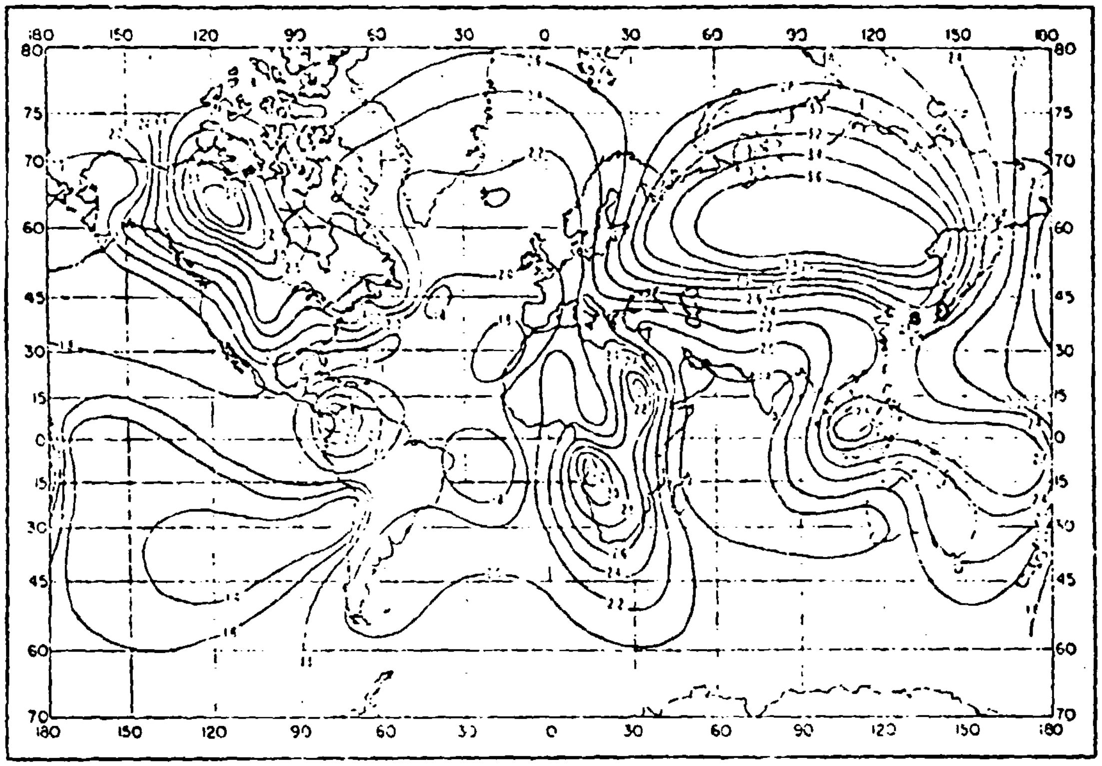
Mean sea-level wet term, W_2: November.



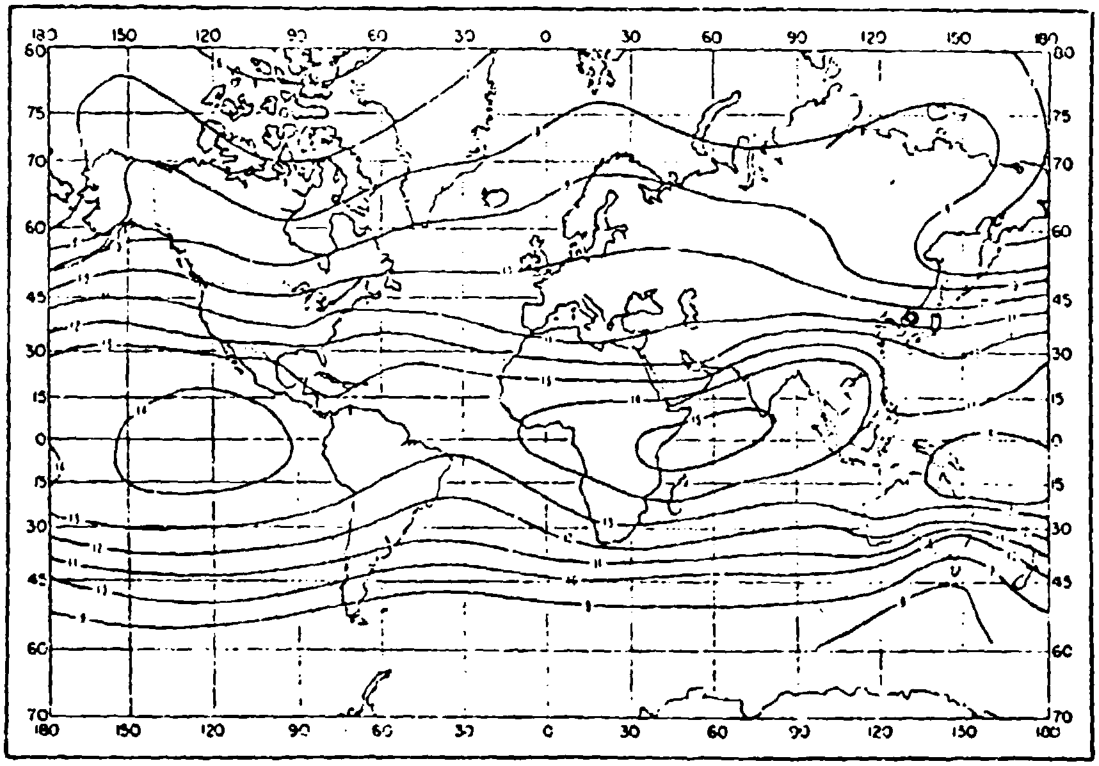
Dry-term tropospheric scale height in km, H_1: November.



Dry-term stratospheric scale height in km, H_2: November.



Wet-term scale height in km, H_w: November.



Mean density tropopause altitude in km, z_t: November.

b. MEAN SURFACE REFRACTIVITY, N_s, AND DIFFERENCE AT 1 KM, $\overline{\Delta N}$

Mean surface refractivity.

Station	Elevation (meters)	Latitude	Longitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Abidjan, Ivory Coast	15	05 15N	03 56W	383	389	389	387	387	382	377	373	380	384	387	383
Adelaide, Australia	11	34 56S	138 35E	318	321	321	321	322	323	322	319	318	313	313	314
Aden, Arabia	4	12 50N	45 01E	365	364	371	380	385	388	379	378	376	372	366	369
Albrook (Balboa), Panama C.Z.	9	08 58N	79 33W	368	360	365	368	375	375	372	381	382	379	378	375
Albuquerque, N. Mex.	1620	35 03N	106 37W	254	251	248	245	253	251	267	274	259	256	251	251
Aldan, U.S.S.R.	680	58 37N	126 22E	297	294	289	284	283	292	305	304	293	287	291	297
Alert, Northwest Territories	62	82 30N	62 20W	326	327	330	321	312	313	313	316	310	313	321	324
Alexander Bay, South Africa	22	28 34S	16 32E	342	341	340	336	330	327	326	325	328	329	334	338
Alger/Maison, Algeria	28	36 43N	03 14E	326	323	327	329	337	316	354	356	354	344	333	328
Alice Springs, Australia	546	23 48S	133 53E	283	287	288	290	290	287	289	281	282	284	285	284
Allahabad, India	98	25 27N	81 44E	327	312	303	291	299	338	385	391	379	353	325	324
Alma Ata, U.S.S.R.	851	43 14N	76 56E	284	283	285	287	293	294	299	295	288	285	288	284
Amundsen-Scott, Antarctica	2800	90 00S	00 00	221	229	243	246	246	248	248	247	244	236	226	220
Anadyr, U.S.S.R.	62	64 47N	177 34E	314	317	319	321	310	312	325	321	313	308	311	314
Anchorage, Alaska	40	61 10N	149 59W	307	307	305	306	308	318	324	324	316	306	307	307
Ankara, Turkey	902	39 57N	32 53E	284	283	283	284	290	292	290	280	287	288	286	287
Antofagasta, Chile	122	23 28S	70 26W	338	341	337	333	330	327	325	327	326	328	332	334
Aoulef, Algeria	290	26 58N	01 05E	294	288	283	280	279	277	274	278	287	291	294	299
Argentia, Newfoundland	17	47 18N	54 00W	311	310	310	313	320	323	335	339	331	320	318	312
Arkhangelsk, U.S.S.R.	13	64 35N	40 30E	312	312	311	311	315	324	331	333	324	316	314	312
Ashkabad, U.S.S.R.	230	37 58N	58 20E	307	305	305	311	305	305	303	306	300	305	305	309
Aswan, United Arab Republic	196	23 58N	32 47E	299	287	280	280	278	276	285	288	291	294	299	305
Athens, Ga.	246	33 57N	83 19W	308	308	312	321	335	352	360	361	347	325	316	308
Athinai, Greece	107	37 58N	23 43E	316	314	316	317	325	325	326	323	326	327	329	322
Auckland, New Zealand	49	36 51S	174 46E	339	345	341	339	339	331	327	329	328	326	329	334
Bahia Blanca, Argentina	72	38 44S	62 11W	320	323	328	320	319	315	316	312	317	321	320	319
Bahrain Island	2	26 16N	50 37E	338	339	342	348	361	365	381	386	382	370	353	341
Baker Lake, Northwest Territories	9	64 18N	96 00W	329	333	326	316	312	314	318	320	314	312	317	326
Bangkok, Thailand	16	13 44N	100 30E	366	377	385	393	393	391	390	391	393	390	374	363
Bangui, Central African Republic	385	04 23N	18 34E	348	347	359	362	361	363	361	362	361	363	362	364
Barrow, Alaska	4	71 18N	156 47W	323	325	325	315	313	316	318	319	315	311	318	324
Beer Ya Aqov, Israel	49	32 00N	34 54E	324	322	323	327	332	339	361	355	347	337	324	323
B-Elan, U.S.S.R.	23	46 57N	142 43E	312	312	311	311	314	326	339	341	331	317	312	311
Beni Abbes/Colomb, Algeria	498	30 08N	02 10W	294	289	283	275	274	274	260	273	284	291	294	296
Benina, Libya	125	32 06N	20 16E	323	322	319	324	324	338	350	349	343	339	331	326
Beograd, Yugoslavia	139	44 48N	20 28E	310	311	308	312	324	331	335	331	320	318	317	312
Bismarck, N. Dak.	506	46 46N	100 45W	296	294	294	289	296	306	313	308	299	293	294	295
Bjornoya Island	14	74 31N	19 01E	310	310	310	312	315	316	320	320	317	312	311	310
Blagoveshchensk, U.S.S.R.	137	50 16N	127 30E	318	311	304	299	304	325	336	339	318	305	307	314
Bloemfontein, South Africa	1422	29 07S	26 11E	283	284	288	277	270	264	265	269	264	267	279	286
Boise, Idaho	871	43 34N	116 13W	284	284	279	280	288	286	283	[illegible]	278	283	285	285
Bombay, India	11	18 54N	72 49E	347	352	362	371	380	386	389	388	384	376	364	355
Bordeaux, France	48	44 51N	00 42W	320	323	322	323	330	337	343	342	343	332	324	321
Brest, France	103	48 27N	04 25W	319	316	318	321	326	332	338	337	336	331	323	324
Brisbane, Australia	41	27 28S	153 02E	351	357	351	343	328	323	319	320	325	326	337	347
Broken Hill, Zambia	1206	14 27S	28 28E	319	322	315	309	293	285	282	278	279	282	305	317
Brownsville, Tex.	8	25 55N	97 28W	337	344	346	359	366	377	376	377	370	357	348	339
Bruxelles, Belgium	100	50 48N	04 21E	314	313	316	317	324	333	338	337	334	328	321	318
Bukhta Tikhaya, U.S.S.R.	6	80 19N	52 48E	326	320	321	316	313	312	314	315	313	311	314	319
Bukhta Tiksi, U.S.S.R.	8	71 35N	128 55E	332	327	324	317	312	316	319*	320	314	311	322	327
Byrd Station, Antarctica	1500	80 00S	120 00W	253	257	259	261	267	266	260	267	262	259	254	253
Cairo, United Arab Republic	68	30 08N	31 24E	314	312	313	313	318	329	311	317	338	331	331	322
Calcutta, India	6	22 39N	88 27E	337	338	346	366	381	390	394	395	394	379	344	341
Camaguey, Cuba	122	21 25N	77 52W	351	353	357	363	370	377	378	379	379	376	365	360
Canton Island	3	02 46S	171 43W	374	372	377	381	377	377	379	376	373	373	373	372
Cape Hatteras, N. C.	3	35 16N	75 33W	319	323	324	337	349	361	376	371	366	347	332	320
Caribou, Maine	191	46 52N	68 01W	307	305	301	305	310	325	342	330	323	313	308	306
Charleville, Australia	299	26 25S	146 17E	325	335	329	324	316	314	309	302	301	304	301	310
Chatham Island	49	43 58S	176 33W	330	339	336	330	327	323	322	321	322	327	329	332
Chiangmai, Thailand	313	18 47N	98 59E	338	332	330	349	368	371	375	377	376	369	356	345
Chita, U.S.S.R.	671	52 05N	113 29E	300	291	287	281	279	297	310	308	293	288	291	295
Christchurch, New Zealand	8	43 32S	172 37E	334	335	337	334	326	324	323	323	324	320	321	327
Clark Field, the Philippines	170	15 08N	120 35E	345	341	345	351	362	367	366	369	368	363	357	349
Cloncurry, Australia	188	20 40S	140 30E	338	339	333	311	310	305	307	299	295	300	304	321
Cocos Island	5	12 05S	96 53E	373	380	372	378	379	376	374	372	372	370	368	369
Columbia, Mo.	239	38 58N	92 22W	305	305	308	312	327	343	358	352	330	310	309	308
Coppermine, Northwest Territories	9	67 49N	115 15W	327	329	328	318	313	318	318	322	310	312	318	323
Coral Harbour, Northwest Territories	59	64 12N	83 22W	324	324	322	312	310	314	317	319	314	309	313	317
Cordoba, Argentina	479	31 19S	64 12W	328	341	332*	321*	318	305	304	298*	300	314	318	327
Curacao Island	16	12 11N	68 58W	372	368	372	376	380	380	382	384	384	382	379	376
Dakar, Senegal	22	14 41N	17 30W	342	342	348	351	358	367	371	377	381	379	360	342
Dar Es Salaam, Tanzania	58	06 52S	39 16E	376	378	382	379	370	362	359	357	361	366	372	375
Darwin, Australia	27	12 26S	130 52E	380	382	387	372	359	338	344	334	360	373	374	385
Denver, Colo.	1625	39 46N	104 53W	251	249	250	249	257	259	264	269	258	253	252	251
D.F. Malan (Capetown), South Africa	49	33 58S	18 36E	337	341	337	333	333	330	329	327	328	330	330	334
Diyarbakir, Turkey	652	37 53N	40 12E	293*	292	293	297	294	289	289	282	276	284	297	294
Djakarta, Indonesia	8	06 11S	106 50E	382	383	382*	383	382	376	367*	366	368	375	380	380
Dodge City, Kans.	791	37 46N	99 58W	248	248	247	291	304	318	332	318	308	294	288	284
Douala, Cameroon	13	04 01N	09 43E	382	382	383	382	382	380	379	379	380	379	381	382
Durban, South Africa	14	29 58S	30 57E	345	357	366	358	345	332	338	339	343	349	357	360

(Continued)

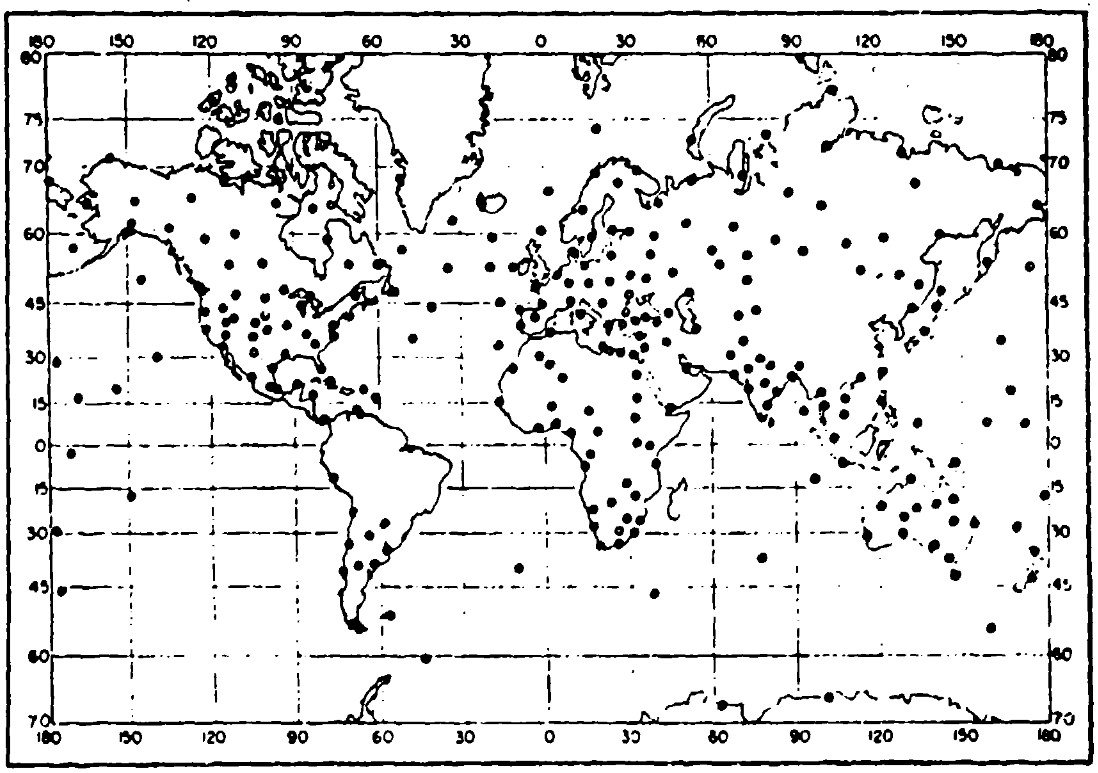
Station	Elevation (meters)	Latitude	Longitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Edmonton, Alberta	676	53 34N	113 31W	290	287	287	286	287	298	307	308	296	288	288	287
Egedesminde, Greenland	48	68 42N	52 52W	311	311	310	309	310	314	318	318	311	309	307	306
El Adem, Libya	157	31 51N	23 56E	314	312	312	314	322	330	337	343	336	329	322	317
El Paso, Tex.	1194	31 48N	106 24W	268	261	258	255	260	266	284	289	274	271	263	262
Ely, Nev.	1908	39 17N	114 51W	249	249	248	247	251	249	248	249	248	249	249	249
Entebbe, Uganda	1146	00 03N	32 27E	320	321	323	325	326	323	321	320	322	320	318	319
Eureka, Northwest Territories	2	80 00N	85 56W	332	335	338	325	313	315	316	316	314	317	327	333
Ezeiza, Argentina	20	34 50S	58 32W	340	349	344	338	331	328	325	326	328	333	335	338
Fairbanks, Alaska	138	64 49N	147 52W	314	309	304	301	304	315	322	322	311	305	308	314
Forrest, Australia	160	30 51S	128 06E	311	319	319	318	315	313	318	316	317	309	300	310
Ft. Lamy, Chad	300	12 08N	15 02E	288	279	282	298	316	337	353	360	358	336	297	294
Ft. Nelson, British Columbia	375	58 50N	122 35W	306	302	296	294	295	307	314	312	305	298	299	303
Ft. Smith, Northwest Territories	203	60 01N	111 58W	315	311	306	302	301	307	316	317	310	306	305	311
Ft. Trinquet, Mauritania	359	25 14N	11 37W	302	301	300	304	306	311	304	313	312	310	309	303
Funchal, Madeira	110	32 38N	16 54W	329	329	324	329	336	345	352	352	349	344	335	330
Gauhati, India	54	26 11N	91 45E	336	332	333	348	368	385	392	394	388	377	356	344
Giles, Australia	614	25 02S	128 18E	292	293	287	283	294	288	287	284	279	286	281	290
Goose Bay, Labrador	44	53 19N	60 25W	310	310	309	308	309	315	324	324	318	310	308	309
Gough Island	40	40 19S	09 54W	334	334	332	328	328	324	324	324	322	324	326	332
Great Falls, Mont.	1115	47 30N	111 21W	272	271	270	269	271	277	278	273	271	270	270	269
Green Bay, Wisc.	210	42 29N	88 08W	306	305	306	308	316	329	338	342	327	316	306	304
Guryev, U.S.S.R.	−21	47 07N	51 55E	315	314	315	314*	316	331*	326	326	320	320*	317	316*
Habbaniya, Iraq	45	33 22N	43 34E	320	318	317	317	311	302	303	306	310	309	321	322
Helsinki, Finland	58	60 19N	24 58E	309	311	311	312	316	325	333	334	327	319	314	311
Hilo, Hawaii	11	19 44N	155 04W	350	349	349	353	358	359	361	367	362	361	358	356
Hobart, Tasmania, Australia	54	42 53S	147 20E	319	323	323	317	315	313	314	314	314	312	312	319
Hong Kong	66	22 18N	114 10E	331	334	348	363	378	385	391	391	383	360	348	334
International Falls, Minn.	360	48 34N	93 23W	301	300	297	296	300	313	323	323	311	303	298	299
Istanbul, Turkey	40	40 58N	29 05E	317	317	318	323	333	342	352	354	342	333	329	321
Izmir, Turkey	25	38 24N	27 10E	317	316	314	319	326	332	334	332	324	328	325	322
Jodhpur, India	224	26 18N	73 01E	301	290	292	284	297	339	365	368	359	310	297	303
Johnston Island	5	16 44N	169 31W	363	361	365	371	366	376	375	375	378	376	371	366
Karachi, West Pakistan	4	24 48N	66 59E	324	341	356	370	384	394	391	391	387	368	350	330
Karaganda, U.S.S.R.	555	49 48N	73 08E	296	297	295	295	296	304	312*	311	296	294	296	257
Kaunas, U.S.S.R.	75	54 53N	23 53E	310	311	310	312	322	327	337	336	327	320	316	312
Keflavik, Iceland	50	63 59N	22 37W	309	310	311	313	317	321	325	323	322	316	313	306
Khabarovsk, U.S.S.R.	72	48 31N	135 10E	316	311	306	306	310	329	346	346	328	310	307	313
Kharkov, U.S.S.R.	153	49 56N	36 17E	309	308	308	308	311	321	325	325	317	317	314	309
Khartoum, Sudan	385	15 36N	32 33E	287	284	283	285	288	305	328	341	329	302	294	293
Khatanga, U.S.S.R.	24	71 59N	102 28E	333	328	320*	316	312	314*	321	317	313	313	325	328
Kirensk, U.S.S.R.	258	57 46N	108 07E	318	312	306	299	301	314	324	324	311	304	309	314
Kobenhavn, Denmark	5	55 38N	12 40E	314	314	315	318	319	325	333	333	329	324	321	316
Kolpashev, U.S.S.R.	76	58 18N	82 54E	316	313	311	309	308	317	333	330	320	311	312	314
Koror, Palau Islands	29	07 20N	134 29E	385	383	383	387	391	388	388	387	388	388	388	387
Krasnoiarsk, U.S.S.R.	194	56 00N	92 53E	309	305	304	301	300	310	327	327	315	305	304	310
Kustanay, U.S.S.R.	171	53 13N	63 37E	310	309	308	305	304	321*	328	320	311	307	307	310
Kyev, U.S.S.R.	182	50 27N	30 30E	308	307	306	307	313	320	324	328	319	314	314	308
La Coruna, Spain	57	42 23N	08 22W	320	321	323	324	331	334	340	342	341	334	324	320*
Lae, New Guinea	8	06 44S	147 00E	378	377	379	381	382	377	377	377	377	376	380	379
Lagos, Nigeria	40	06 35N	03 20E	377	382	382	384	385	378	373	372	379	382	381	379
Lake Charles, La.	5	30 13N	93 09W	325	328	330	346	362	375	382	380	369	350	333	329
Las Vegas, Nev.	664	36 05N	115 09W	283	279	274	260	267	264	279	284	271	275	278	280
Leningrad, U.S.S.R.	4	59 58N	30 18E	312	312	312	312	318	327	334	334	327	320	315	313
Leopoldville (Kinshasa), Democratic Republic of the Congo	390	04 19S	15 19E	369	368	368	367	368	355	345	345	352	360	364	367
Lerwick, United Kingdom	82	60 08N	01 11W	314	315	315	316	320	324	329	330	328	324	318	313
Lima, Peru	135	12 05S	77 02W	354	367	354	360	343	339	338	338	339	340	342	349
Lindenberg, East Germany	105	52 13N	14 07E	311	313	312	313	319	325	336	332	325	322	317	313
Lisboa, Portugal	103	38 46N	09 08W	325	328	328	324	329	330	335	338	341	330	328	327
Lourenco Marques, Portuguese East Africa	44	25 55S	32 34E	371	370	366	361	348	341	339	341	345	358	367	362
Luanda, Portuguese West Africa	70	08 49S	13 13E	376	374	377	380	369	354	351	352	359	367	375	374
Lvov, U.S.S.R.	329	49 49N	23 57E	302	306	301	307	315	322	330	327	318	312	309	304
Macquarie Island	6	54 30S	158 57E	320	319	319	317	316	314	315	316	315	314	312	320
Madras, India	16	13 00N	80 11E	364	363	368	379	379	367	360	370	340	384	379	365
Madrid, Spain	657	40 24N	03 41W	296	296	296	291	300	304	298	299	308	304	306	301
Majuro Island	3	07 05N	171 23E	383	378	381	385	387	381	383	383	383	383	384	383
Malakal, Sudan	390	09 33N	31 39E	298	292	299	320	337	353	358	362	363	358	329	304
Malye-Karmakuly, U.S.S.R.	16	72 23N	52 44E	311*	315	312	312	311	316	322*	321*	—	312*	314*	314*
Maracay, Venezuela	412	10 15N	67 39W	339	335	330	345	351	362	363	353	354	355	350	344
Marion Island	26	46 53S	37 52E	317	317	319	315	313	313	313	314	313	314	314	313
Maun, South Africa	945	19 59S	23 25E	323	324	319	301	284	279	275	271	274	282	308	321
Mawson, Antarctica	14	67 36S	62 53E	299	298	300	303	305	306	306	306	303	300	298	299
Mazatlan, Mexico	78	23 11N	106 25W	340	339	342	351	360	374	379	380	384	377	364	340
McMurdo Sound, Antarctica	45	77 51S	166 40E	302	301	310	307	310	311	312	315	308	301	299	293
Medford, Oreg.	405	42 23N	122 52W	305	303	301	300	305	307	306	305	306	307	307	307
Melbourne, Australia	44	37 49S	144 58E	328	328	330	325	321	324	322	319	320	319	324	322
Merida, Mexico	22	20 58N	89 31W	350	349	354	363	369	376	379	378	381	370	357	351
Mersa Matruh, United Arab Republic	28	31 20N	27 14E	319	319	321	323	338	348	361	361	348	340	334	323
Miami, Fla.	4	25 49N	80 17W	341	343	347	357	367	375	379	379	388	362	352	316
Milano, Italy	120	45 28N	09 17E	313	315	316	319	330	340	348	348	340	329	319	316
Moscow, U.S.S.R.	156	55 49N	37 37E	307	306	305	306	314	322	332	327	318	313	310	307

Station	Elevation (meters)	Latitude	Longitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Mould Bay, Northwest Territories	15	76 14N	119 20W	331	330	332	322	314	314	316	317	312	313	323	328
Murmansk, U.S.S.R.	50	68 58N	33 03E	309	309	308	308	310	315	324	323	317	313	311	300
Mys Cheliuskin, U.S.S.R.	13	77 43N	104 17E	328	324	326	318	311	315	317	316	314	312	320	321
Mys Kamenny, U.S.S.R.	7	68 28N	73 34E	319	321	318	314	313	316	321	327	314*	314	315	322
Mys Schmidt, U.S.S.R.	7	68 55N	179 29W	322	326	325	318	313	317	318	318	316	312	315	320*
Nagphur, India	310	21 06N	79 07E	319	300	297	305	308	343	370	369	361	341	321	317
Nairobi, Kenya	1798	01 18S	36 45E	277	278	277	289	289	282	281	280	277	278	284	286
Nandi, Fiji Islands	16	17 45S	177 27E	380	382	381	379	373	367	364	362	367	367	371	373
Nantucket, Mass.	14	41 15N	70 04W	311	312	312	318	327	340	356	354	347	330	320	313
Naryan-Mar, U.S.S.R.	7	67 39N	53 01E	313	313	312	312	313	315	325	325	316	313	313	315
Nashville, Tenn.	184	36 07N	86 41W	309	311	311	324	338	351	363	361	340	326	313	312
Naval Orcades Island	4	60 45S	44 43W	309	304	307	303	307	307	309	306	307	307	307	307
Neuquen, Argentina	270	38 57S	68 07W	296	300	305*	310*	304	300	304	302	299	300	297	296
New Delhi, India	216	28 35N	77 12E	313	311	308	299	306	334	373	379	362	332	318	313
Niamey, Niger	224	13 29N	02 10E	284	281	285	308	331	351	362	369	369	343	308	294
Nicosia, Cyprus	218	35 09N	33 17E	317	315	313	314	315	325	326	331	325	318	320	319
Nitchequon, Quebec	515	53 12N	70 35W	298	298	293	291	293	299	311	307	301	296	292	295
Nome, Alaska	14	64 30N	165 26W	313	316	315	313	313	320	328	326	318	311	312	315
Norfolk Island	110	29 03S	167 56E	352	357	349	348	336	336	331	334	333	337	340	348
Norman Wells, Northwest Territories	64	65 15N	126 51W	322	321	317	310	308	314	327	325	315	309	315	318
North Platte, Nebr.	850	41 08N	100 42W	282	281	281	282	295	307	317	314	294	289	283	281
Norway Base, Antarctica	50	70 20S	02 00W	302	303	303	309	309	311	313	311	309	305	301	302
Nouvelle Amsterdam Island	28	37 50S	77 34E	340	339	336	333	332	324	327	328	325	328	330	339
Oakland, Calif.	6	37 44N	122 12W	323	324	324	326	329	334	337	337	335	330	323	321
Odessa, U.S.S.R.	64	46 29N	30 38E	312	313	312	315	327	334	337	336	326	323	321	315
Okhotsk, U.S.S.R.	7	59 22N	143 12E	316	314	311	309	312	320	332	337	321	307	310	314
Omsk, U.S.S.R.	94	54 58N	73 24E	315	312	311	309	305	316	331	328	316	307	311	313
Onslow, Australia	4	21 40S	115 07E	344	350	355	342	327	330	321	317	322	316	325	337
Ostersund, Sweden	309	63 11N	14 37E	299	299	299	299	301	310	313	314	310	304	302	294
Ostrov Chetyrekhstolbovoy, U.S.S.R.	6	70 38N	162 24E	325	327	326	317	312	315	316	317	315	313	319	324
Ostrov Dikson, U.S.S.R.	20	73 30N	80 14E	324	323	318	315	313	315*	320	320	314	311	316	320
Papeete, Tahiti Island	2	17 33S	149 37W	375	376	378	377	378	368	366	362	363	368	373	375
Perth, Australia	60	31 57S	115 49E	330	330	333	330	327	326	326	323	323	314	320	324
Peshawar, West Pakistan	359	34 01N	71 35E	303	301	309*	312	304	305	347*	345*	373*	315	311	304
Petropavlovsk Kamcatskij, U.S.S.R.	7	52 58N	158 45E	303	304	306	305	309	320	326	331	320	311	306*	303
Ponape, Caroline Islands	37	06 58N	158 13E	379	380	380	384	385	386	384	384	384	384	384	378
Port Blair, India	79	11 40N	92 43E	364	345	369	371	385	384	382	386	384	382	378	367
Port Elizabeth, South Africa	61	33 59S	25 36E	351	350	350	339	331	328	329	325	332	335	339	346
Port Harrison, Quebec	20	58 27N	78 08W	319	318	317	312	313	315	321	322	317	313	310	314
Pretoria, South Africa	1368	25 45S	28 14E	301	300	298	287	275	270	270	266	276	282	294	299
Puerto Montt, Chile	3	41 28S	72 56W	338	337	331	328	326	328	326	324	325	326	324	331
Quetta/Samungli, West Pakistan	1601	30 15N	66 53E	263	258	267	269	262	276	282	278	270	261	256	259
Raizet, Guadaloupe Island	8	16 16N	61 31W	368	361	363	369	370	374	377	379	380	377	374	369
Raoul Island	49	29 15S	177 55W	349	352	353	348	342	334	331	331	333	338	338	346
Resistencia, Argentina	52	27 28S	58 59W	356	352	362	353	346	332	329	332	337	315	342	354
Resolute Bay, Northwest Territories	64	74 43N	94 59W	325	329	330	319	311	313	315	315	310	310	319	320
Roma, Italy	131	41 48N	12 34E	314	317	316	319	328	334	338	339	335	328	321	318
Saigon, Viet Nam	10	10 49N	106 40E	363	362	369	375	384	386	384	386	384	383	373	370
Saint Paul, Alaska	6	57 09N	170 13W	313	311	311	312	314	320	328	328	322	318	311	312
Salisbury, Rhodesia	1480	17 56S	31 05E	302	305	295	288	279	277	271	270	274	275	288	300
Salt Lake City, Utah	1288	40 46N	111 58W	270	268	266	264	264	267	270	272	265	264	270	271
Samarovo, U.S.S.R.	37	60 58N	69 04E	316	312	311	309	310	321	330	329	318	311	314	315
Samsun, Turkey	44	41 17N	36 20E	311	313	316	320	340	343	346	347	337	329	322	313
San Diego, Calif.	9	32 44N	117 10W	320	328	325	328	332	339	346	350	346	337	323	317
San Juan, P. R.	19	18 26N	66 00W	358	358	359	363	371	376	378	378	378	374	379	366
Sapporo, Japan	18	43 03N	141 20E	309	309	310	310	318	332	349	353	337	323	313	309
Saratov, U.S.S.R.	135	51 34N	46 00E	304	305	303	305	307	315	322	318	314	307	305	304
Sault Ste. Marie, Mich.	221	46 28N	84 22W	307	305	304	305	309	325	333	342	323	315	307	308
Shemya, Alaska	37	52 43N	174 06E	308	308	311	315	318	321	327	327	324	315	310	307
Singapore	14	01 21N	103 54E	378	377	382	385	387	384	383	382	382	382	380	381
Sodankyla, Finland	179	67 22N	26 39E	306	304	306	304	305	309	319	320	313	307	307	306
Stanley, Falkland Islands	53	51 42S	57 52W	317	318	318	316	313	312	313	311	312	312	314	314
Stockholm, Sweden	52	59 21N	18 04E	311	310	310	311	311	318	328	329	324	321	315	312
Stuttgart, Germany	315	48 50N	09 12E	303	303	304	306	313	310	322	325	319	312	306	302
Sverdlovsk, U.S.S.R.	264	56 50N	60 38E	306	303	302	300	302	314	324	319	309	303	305	304
Swan Island	10	17 24N	83 56W	368	364	371	377	382	386	387	387	388	383	375	371
Syktyvkar, U.S.S.R.	96	61 40N	50 51E	311	309	308	308	310	317	328	324	314	313	311	311
Tacubaya, Mexico	2308	19 24N	99 12W	249	247	242	247	252	263	266	266	265	258	254	251
Taipei, Taiwan	8	25 02N	121 31E	338	342	349	357	372	381	384	384	380	364	357	343
Tamanrasset, Algeria	1378	22 48N	05 32E	246	244	244	243	213	262	261	262	258	251	252	250
Tananarive, Malagasy Republic	1310	18 54S	47 32E	312	311	312	307	299	295	291	289	290	294	306	311
Tashkent, U.S.S.R.	478	41 20N	69 18E	298	295	298	304	308	301	302	304	297	297	300	300
Tatoosh Island, Wash.	28	48 23N	124 44W	318	321	317	321	328	332	330	340	336	328	324	321
Tbilisi, U.S.S.R.	401	41 43N	44 48E	299	297	298	305	314	320	331	330	321	311*	304	303
The Pas, Manitoba	272	53 58N	101 06W	310	305	302	301	304	316	328	325	312	305	303	306
Tourane, Viet Nam	7	16 02N	108 11E	365*	364	372*	382*	385*	383*	385*	390*	389*	388*	376*	363*
Townsville, Australia	4	19 15S	146 45E	376	378	371	363	351	339	333	336	339	356	361	364
Trivandrum, India	64	08 29N	76 57E	362	364	370	380	385	382	382	380	379	380	378	368
Tromso, Norway	9	69 42N	19 01E	307	309	311	310	318	321	328	328	321	313	312	308
Tura, U.S.S.R.	147	64 16N	100 14E	334	326	307*	304	301*	313	324	318	310	306	316*	329

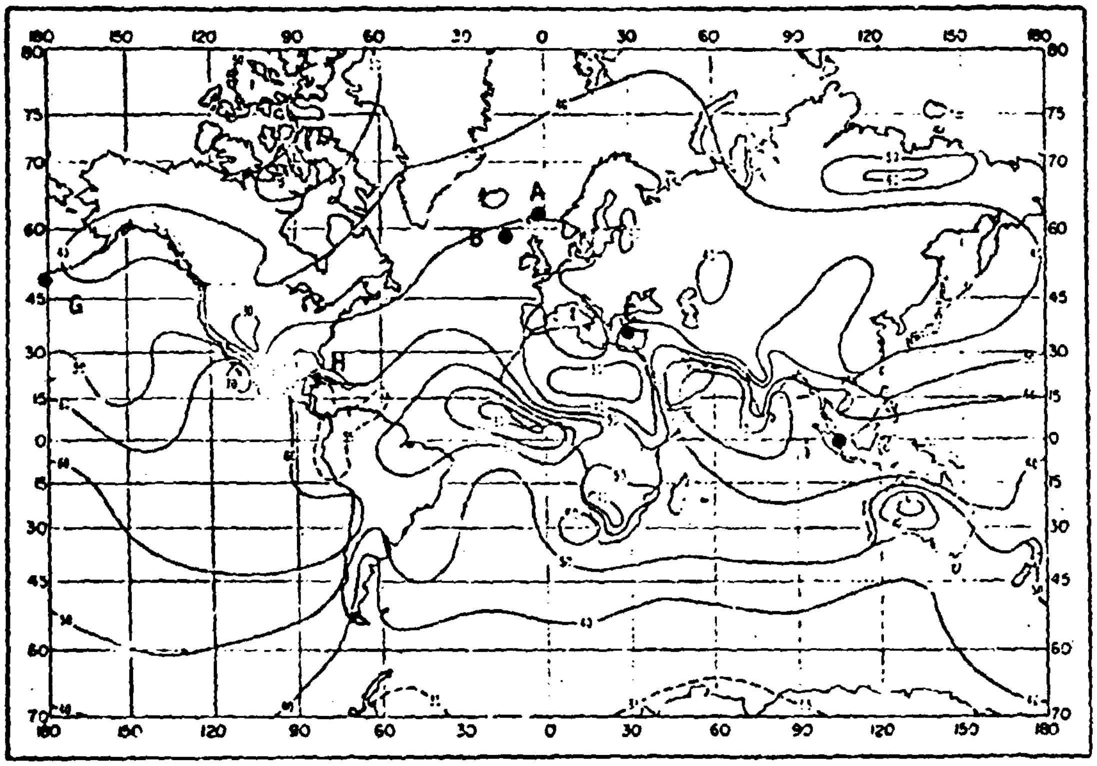
(Continued)

Station	Elevation (meters)	Latitude	Longitude	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Turukhansk, U.S.S.R.	37	65 47N	87 57E	324	318	312	308	305	311	323	324	316	310	316	324
Ushuaia, Argentina	6	54 48S	68 19W	311	312	307	308	308	310	310	308	309	305	305	303
Valentia, United Kingdom	14	51 56N	10 15W	320	319	321	322	325	332	337	336	335	329	324	320
Valparaiso, Chile	41	33 01S	71 39W	345	345	343	334	332	332	331	332	332	334	335	338
Vera Cruz, Mexico	16	19 12N	96 08W	361	367	370	380	382	386	386	387	383	379	368	361
Verkhoyansk, U.S.S.R.	135	67 33N	133 23E	345	341	320	307	301	309	315	314	307	310	331	345
Vishakhapatnam, India	3	17 43N	83 14E	357	356	369	391	392	391	384	386	389	380	358	353
Vladivostok, U.S.S.R.	138	43 07N	131 54E	308	305	304	307	314	329	347	350	332	311	304	308
Vologda, U.S.S.R.	118	59 17N	39 52E	309	308	307	308	312	325	335	330	319	314	311	309
Wajima, Japan	7	37 23N	136 54E	314	314	316	322	332	348	359	371	356	336	324	318
Wake Island	4	19 17N	166 39E	356	359	363	367	371	378	380	384	383	380	372	368
Washington, D. C.	20	38 51N	77 02W	310	311	309	320	328	342	354	352	343	328	316	313
Whitehorse, Yukon	698	60 43N	135 04W	291	287	284	282	282	287	292	293	289	284	284	289
Wien/Hohe-Warte, Austria	203	48 15N	16 22E	308	307	307	309	316	325	332	333	322	317	312	308
Wilkes Stn., Antarctica	12	66 15S	110 35E	301	302	300	303	303	306	307	303	303	301	299	302
Windhoek, South-West Africa	1728	22 34S	17 06E	263	269	267	265	248	247	245	241	237	240	256	260
Ship A	‡	62 00N	33 00W	307	312	312	315	317	323	326	324	320	314	311	308
Ship B	‡	56 30N	51 00W	310	310	312	312	318	321	326	325	320	315	311	309
Ship C	‡	52 45N	35 30W	317	315	315	321	322	328	332	333	330	323	319	318
Ship D	‡	44 00N	41 00W	327	323	324	328	334	340	356	360	348	336	330	330
Ship E	‡	35 00N	48 00W	339	336	337	341	351	366	374	374	368	357	349	346
Ship I	‡	59 00N	19 00W	316	315	316	319	321	327	330	328	324	320	319	315
Ship J	‡	52 30N	20 00W	322	319	321	323	324	333	337	337	333	327	326	319
Ship K	‡	45 00N	16 00W	329	322	327	329	335	342	348	348	345	338	330	332
Ship M	‡	66 00N	02 00E	312	314	315	316	319	321	327	327	326	318	318	312
Ship N	‡	30 00N	140 00W	340	339	335	338	340	344	349	351	350	348	345	342
Ship P	‡	50 00N	145 00W	316	318	318	317	324	328	333	336	335	325	319	317
Ship V	‡	34 00N	164 00E	328	331	335	340	350	359	379	381	369	366	355	337

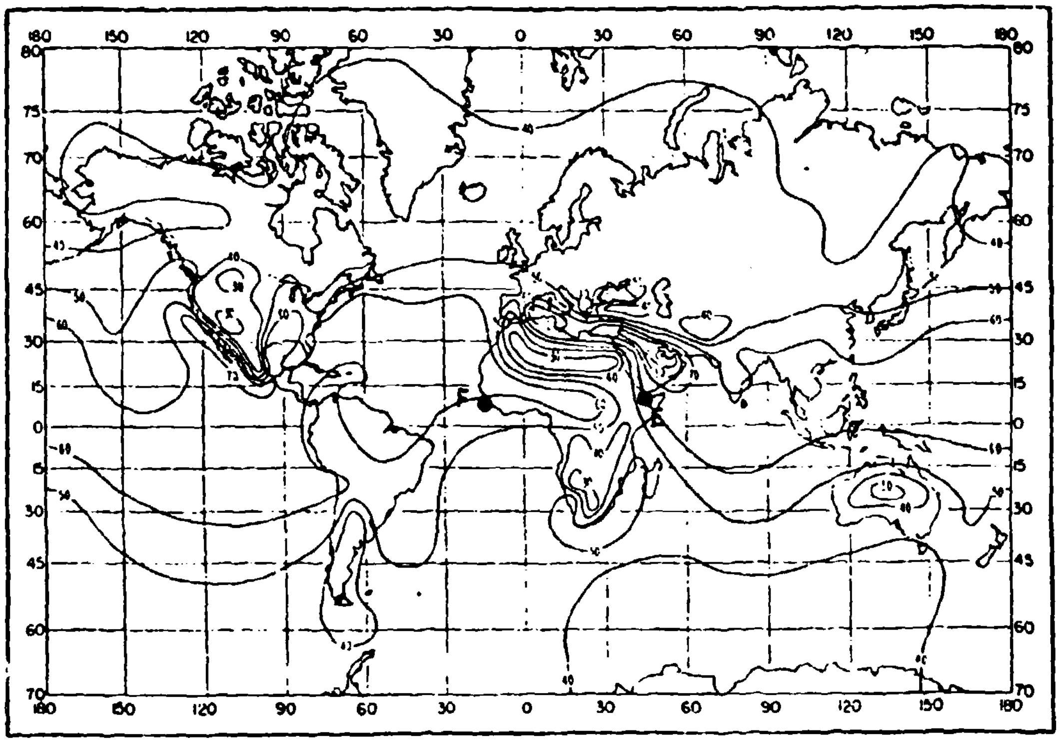
* *Less than 5 years of data.*
‡ *No elevation given.*



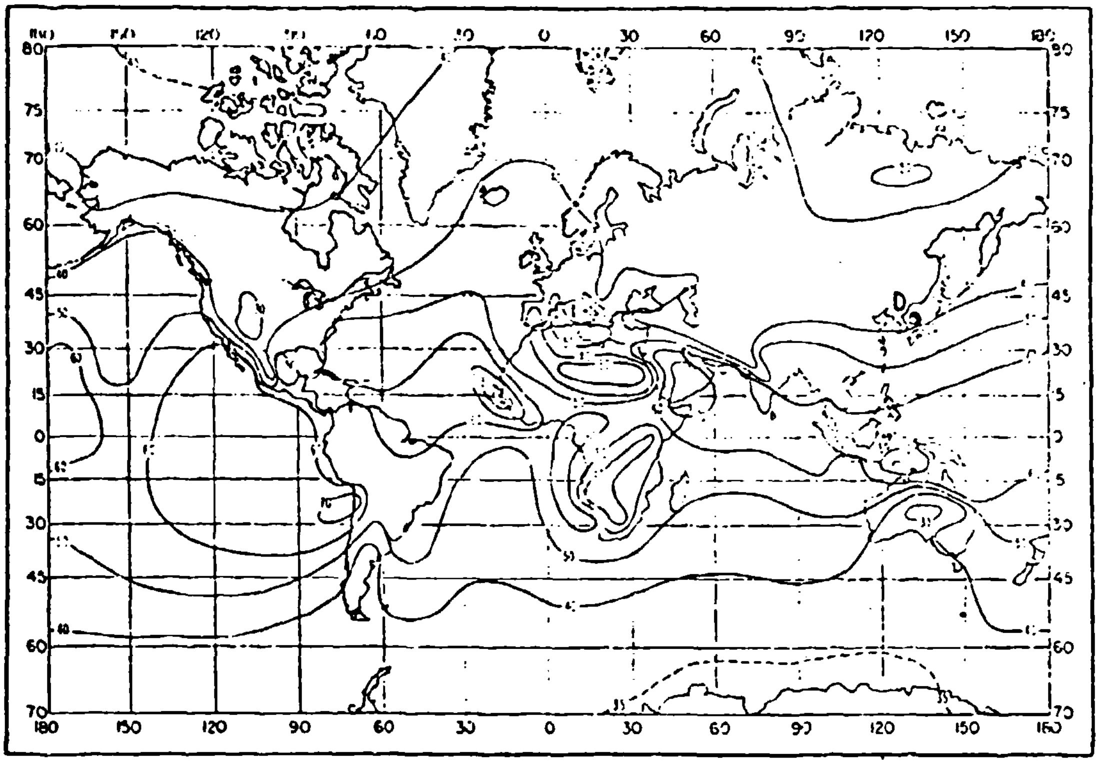
Location of ΔN data stations.



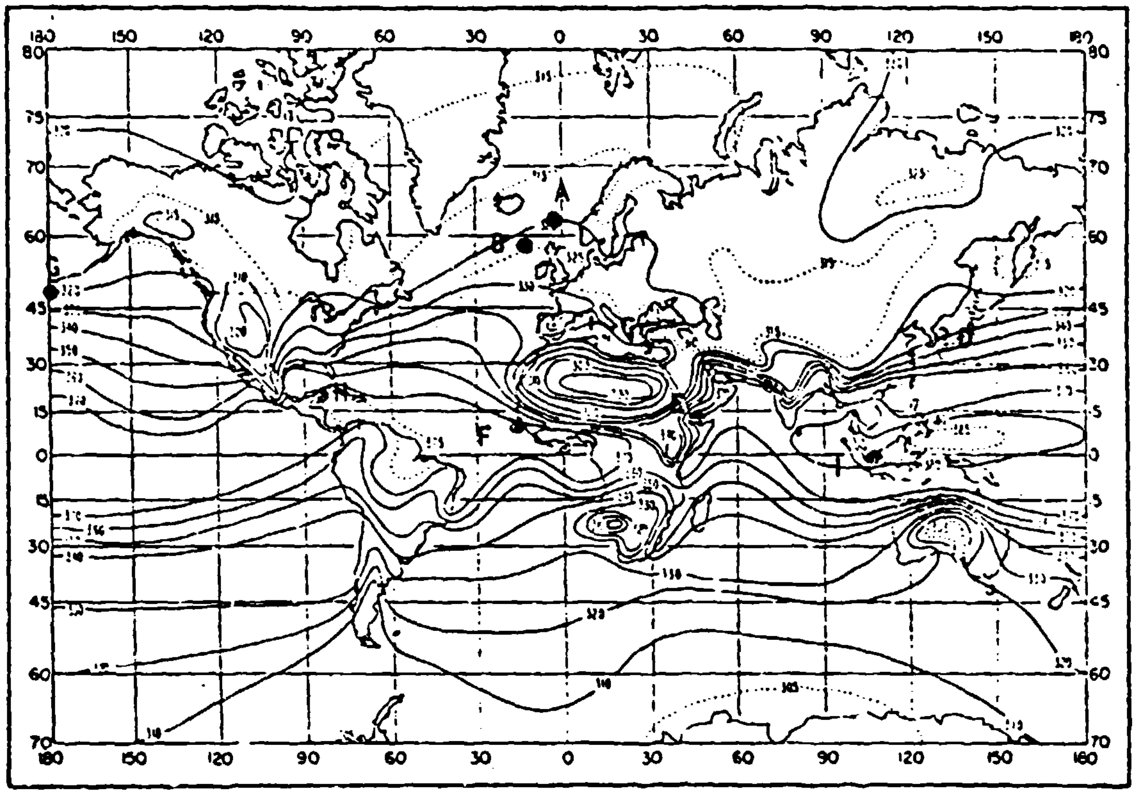
Monthly mean ΔN: February.



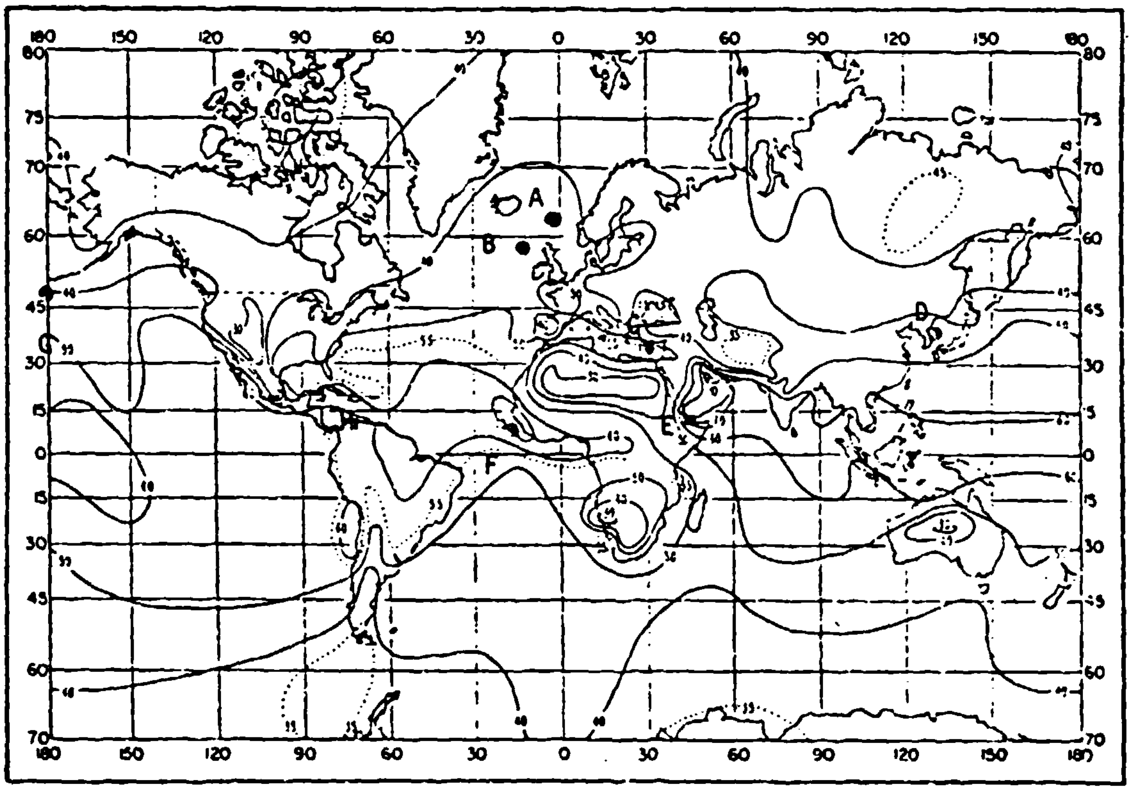
Monthly mean ΔN: August.



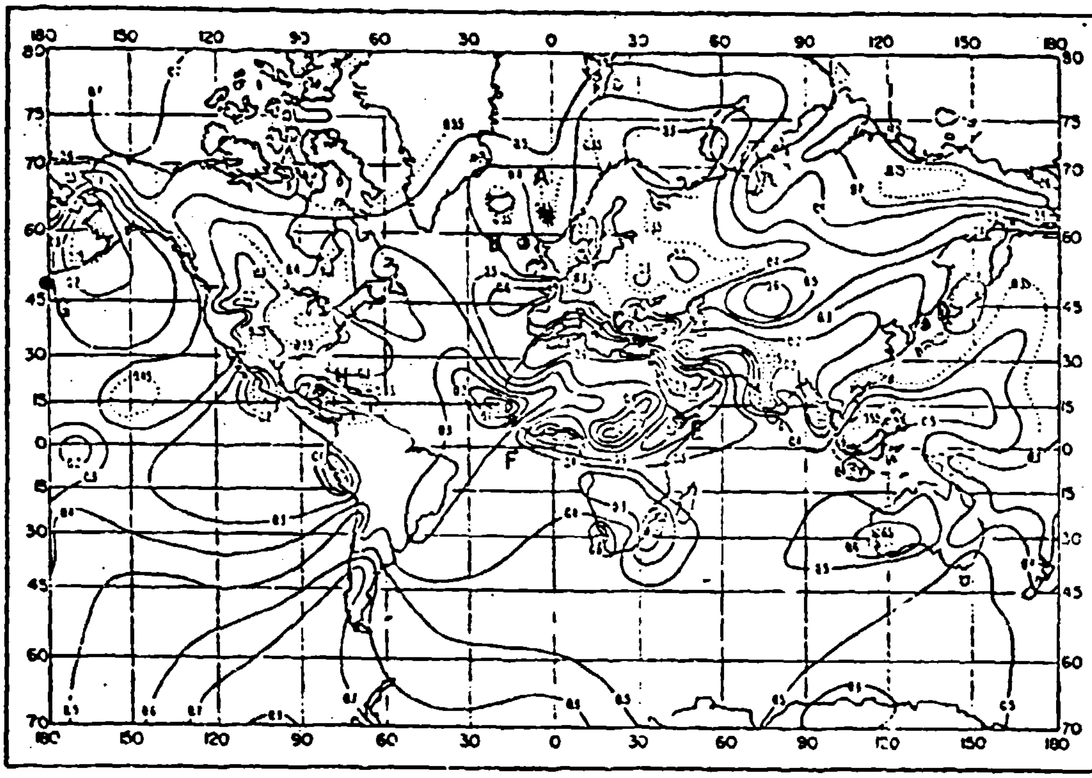
Monthly mean ΔN: November.



Annual mean of sea-level refractivity, $\overline{\overline{N}}_o$.

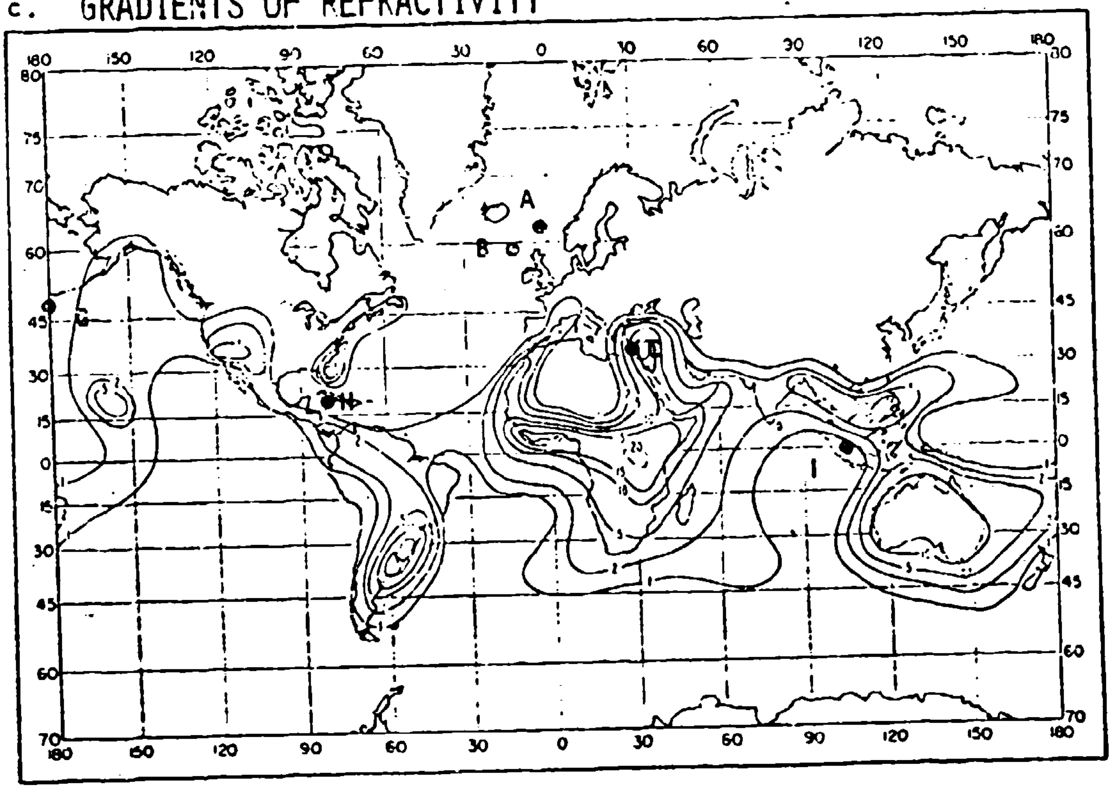


Annual mean of refractivity gradient between surface and 1 km, $\overline{\overline{\Delta N}}$.

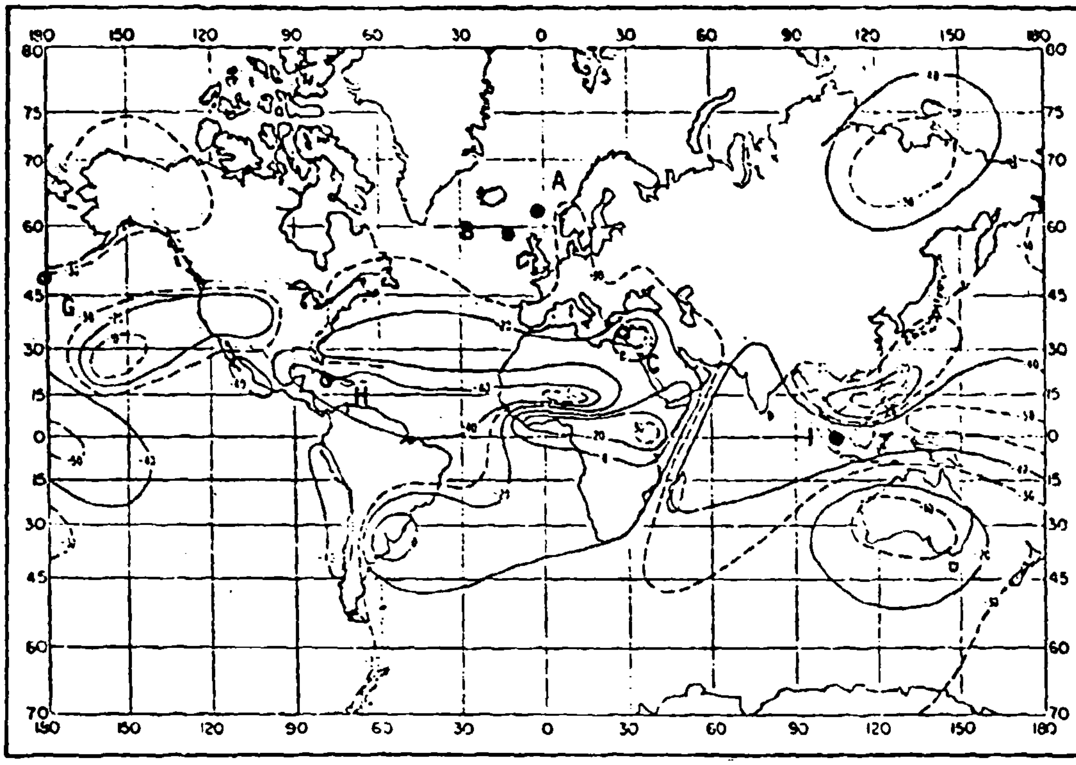


Slope of regression line of $\overline{\Delta N}$ *versus* $\overline{N}_s$, b.

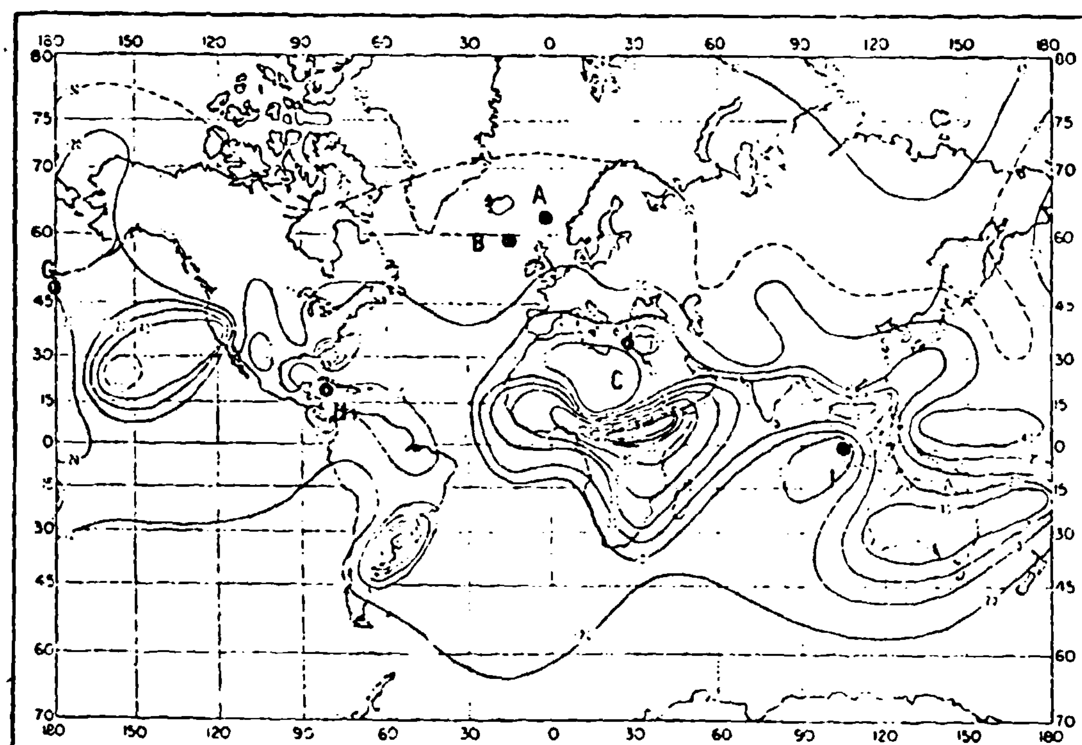
c. GRADIENTS OF REFRACTIVITY



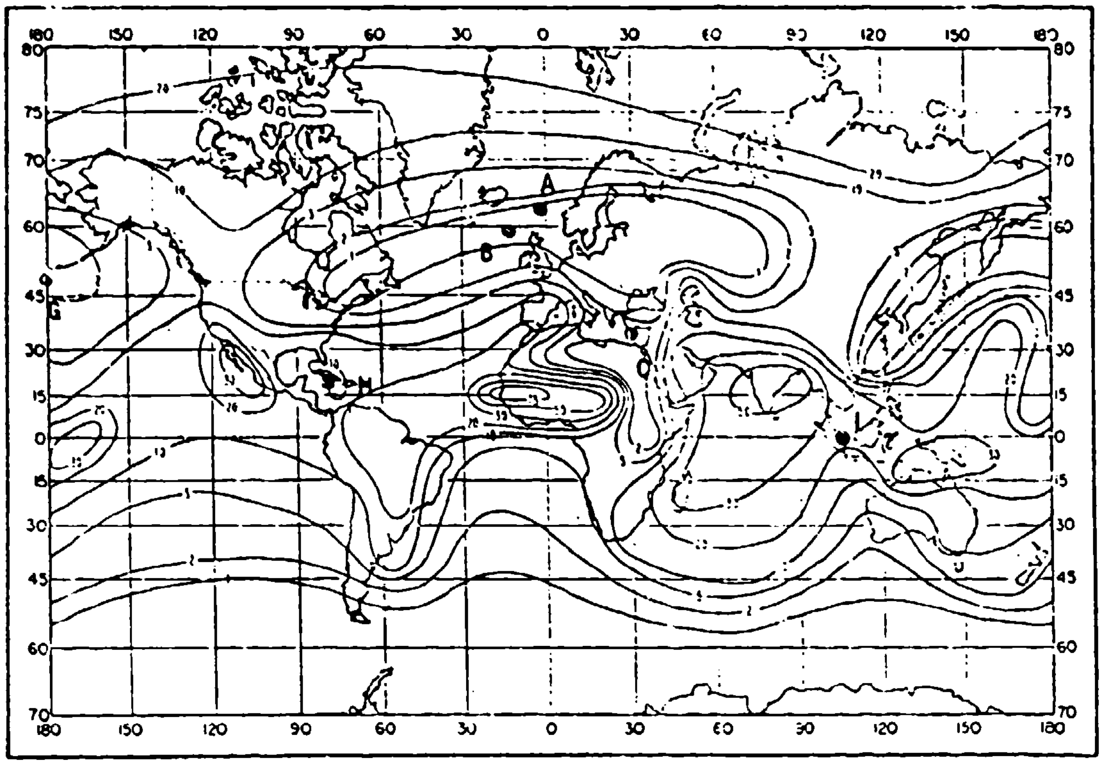
Percent of time gradient ≥ 0 (N/km): February.



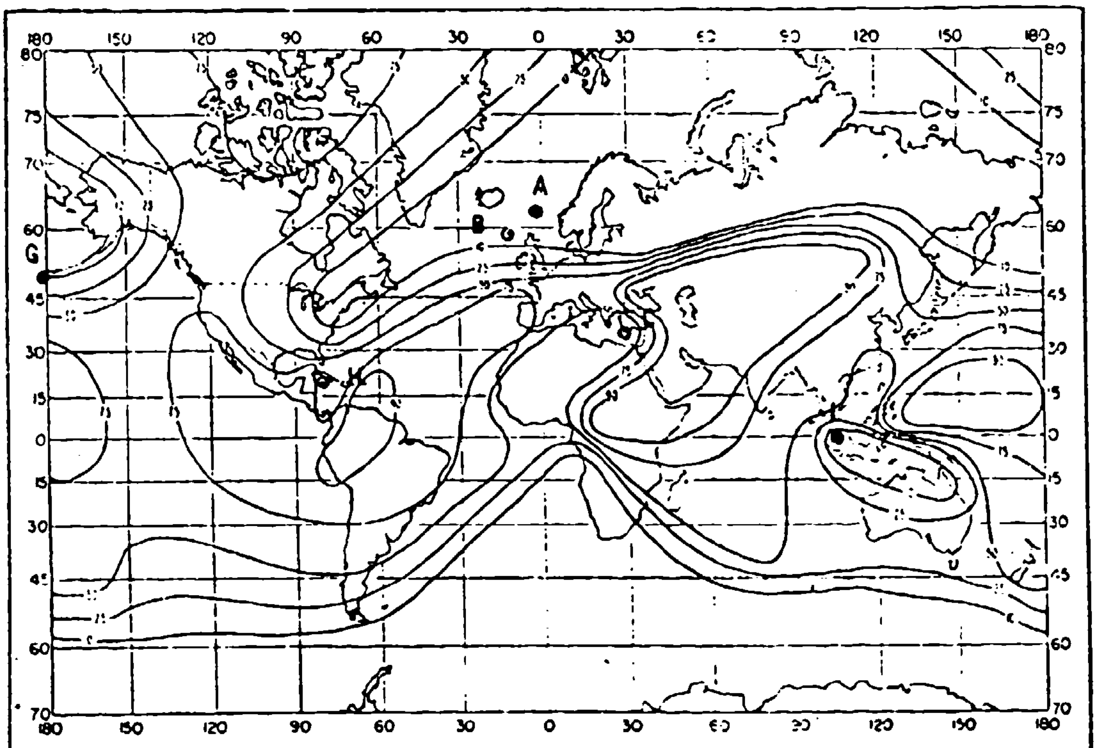
Gradient (N/km) exceeded 10 percent of the time for 100-m layer: February.



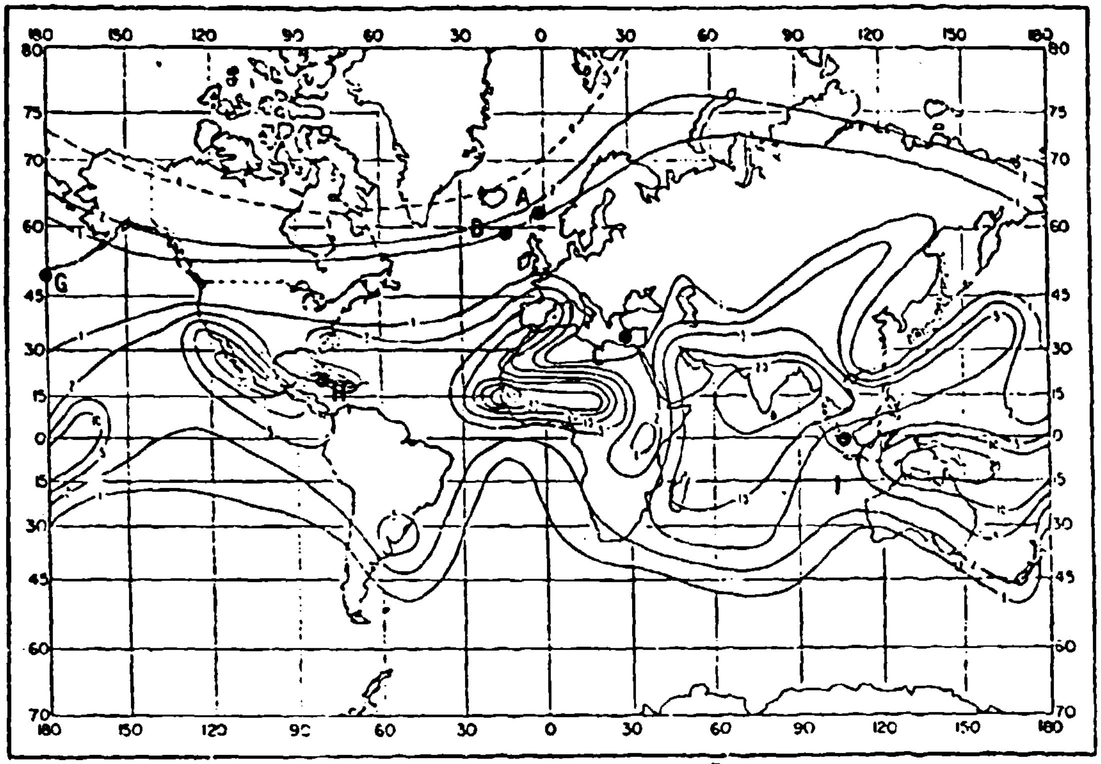
Gradient (N/km) exceeded 2 percent of the time for 100-m layer: February.



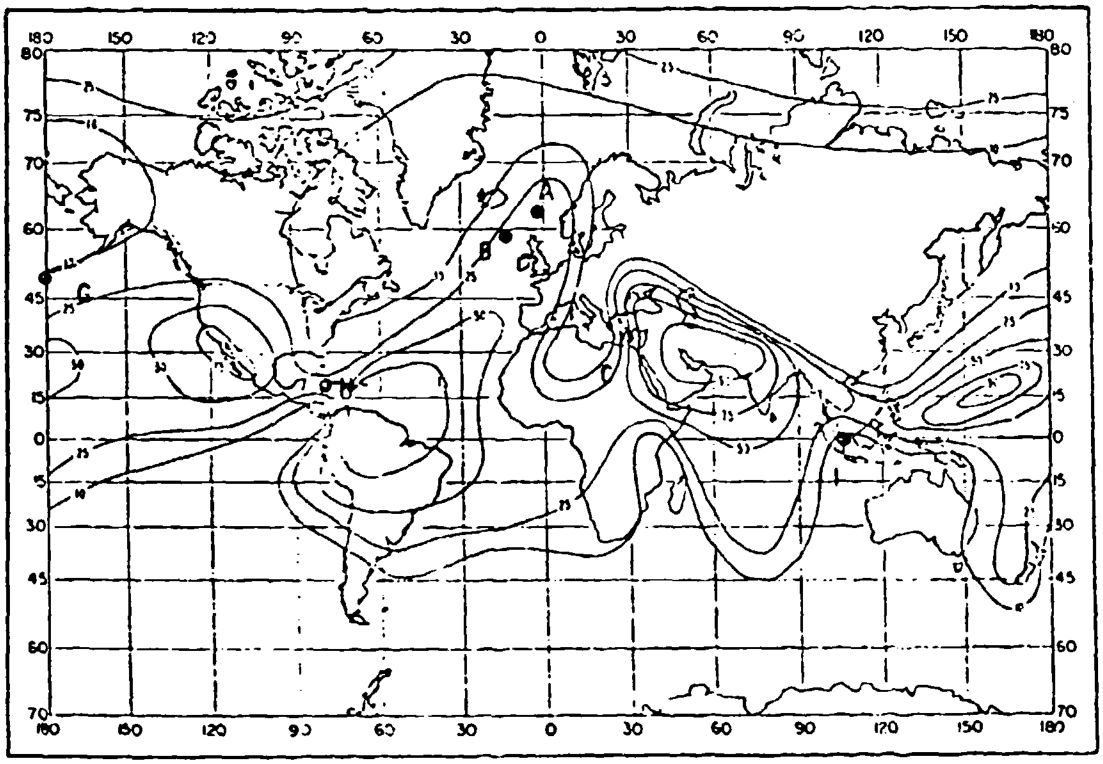
Percent of time gradient ≤ −100 (N/km): February.



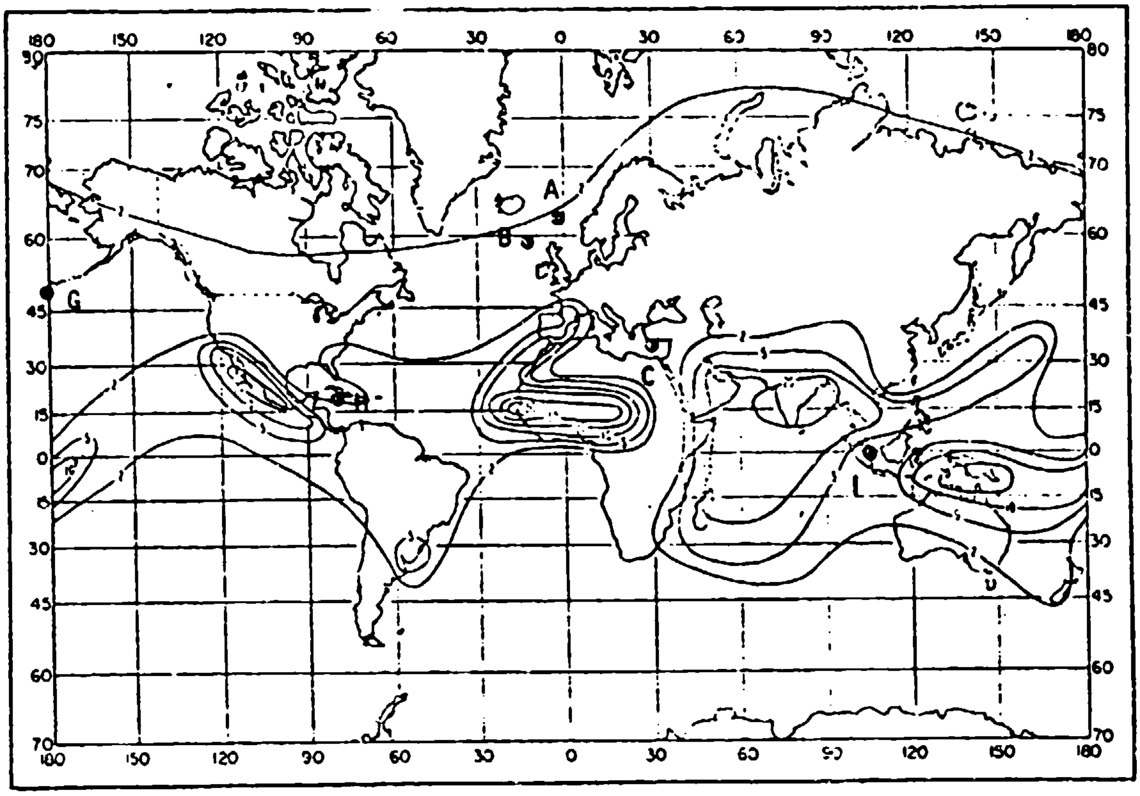
Percent of superrefractive layers thicker than 100 m: February.



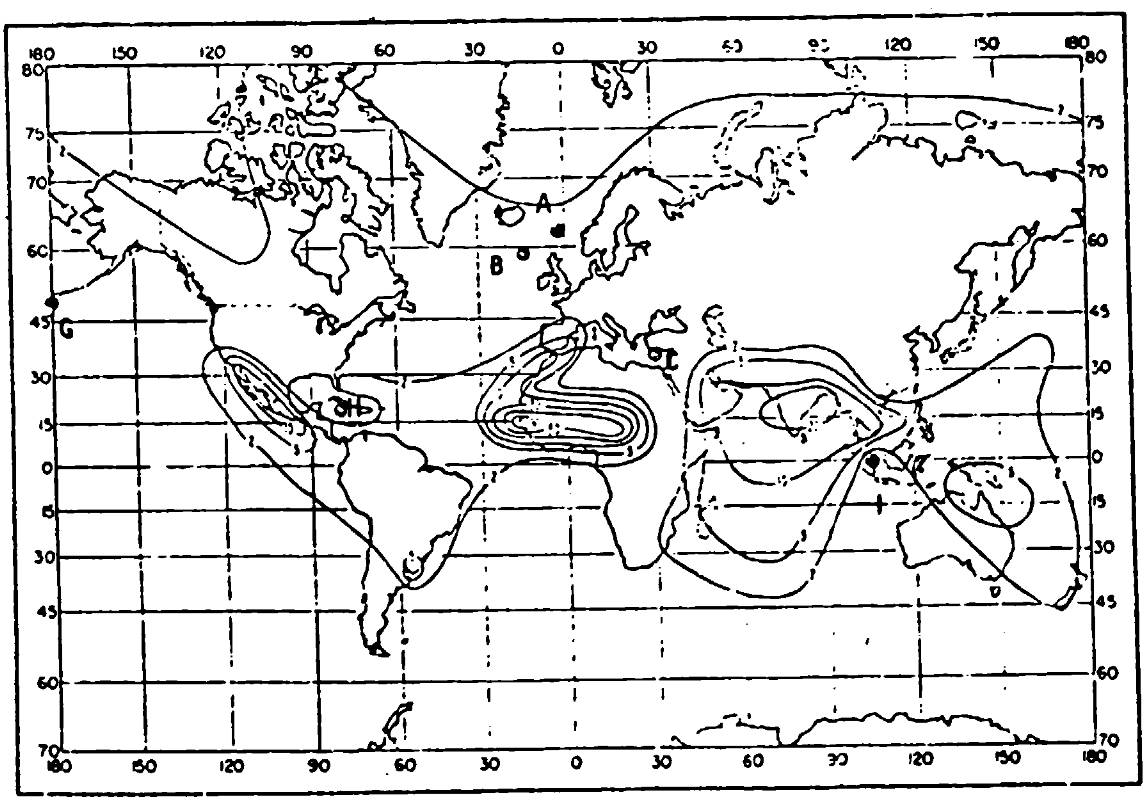
Percent of time gradient ≤ −157 (N/km): February.



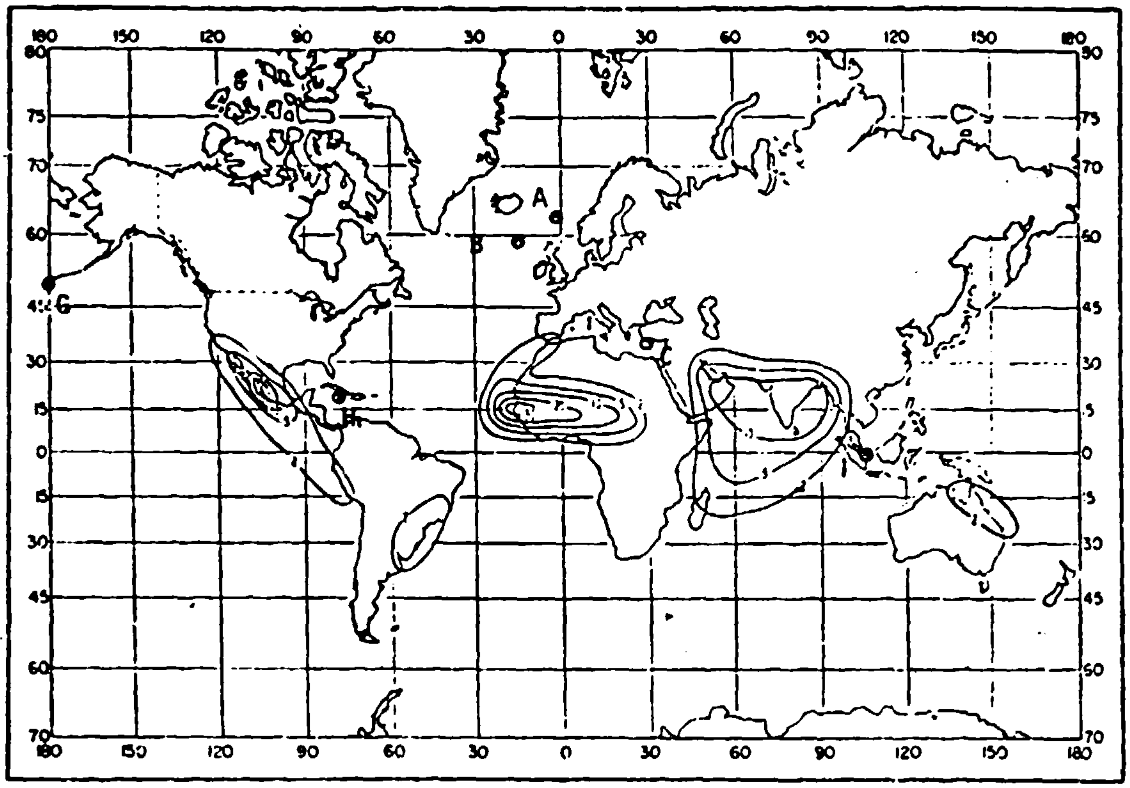
Percent of ducting layers thicker than 100 m: February.



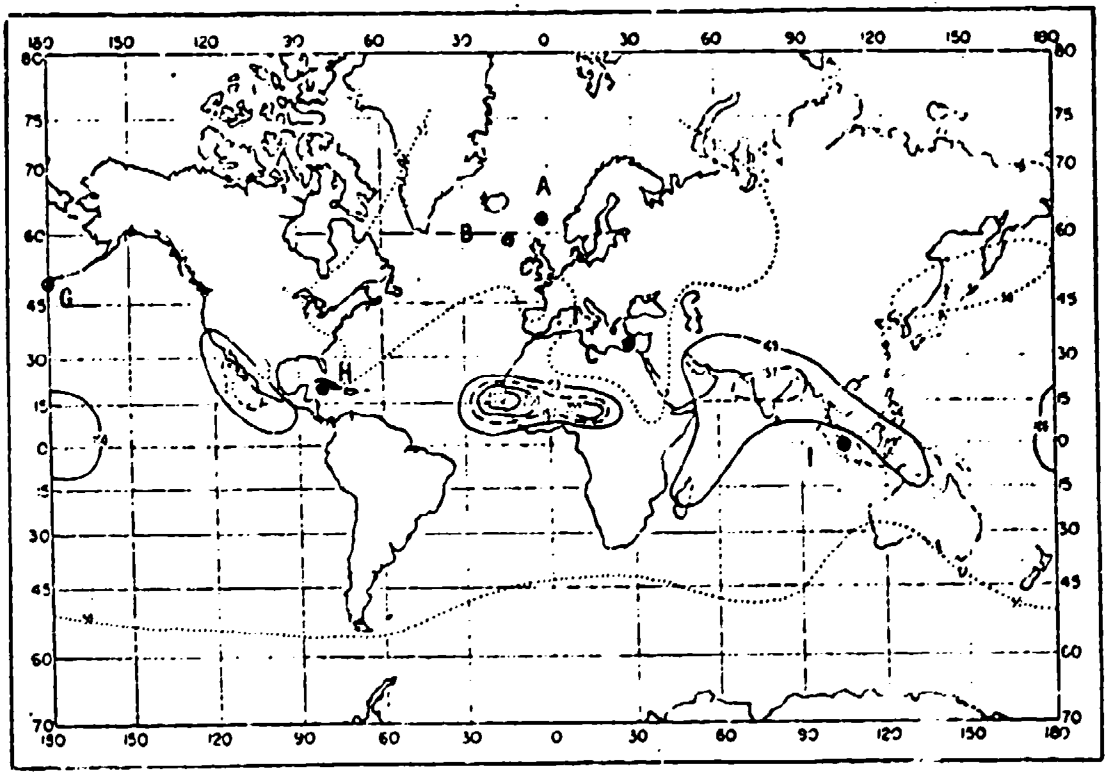
Percent of time trapping frequency < 3000 Mc's: February.



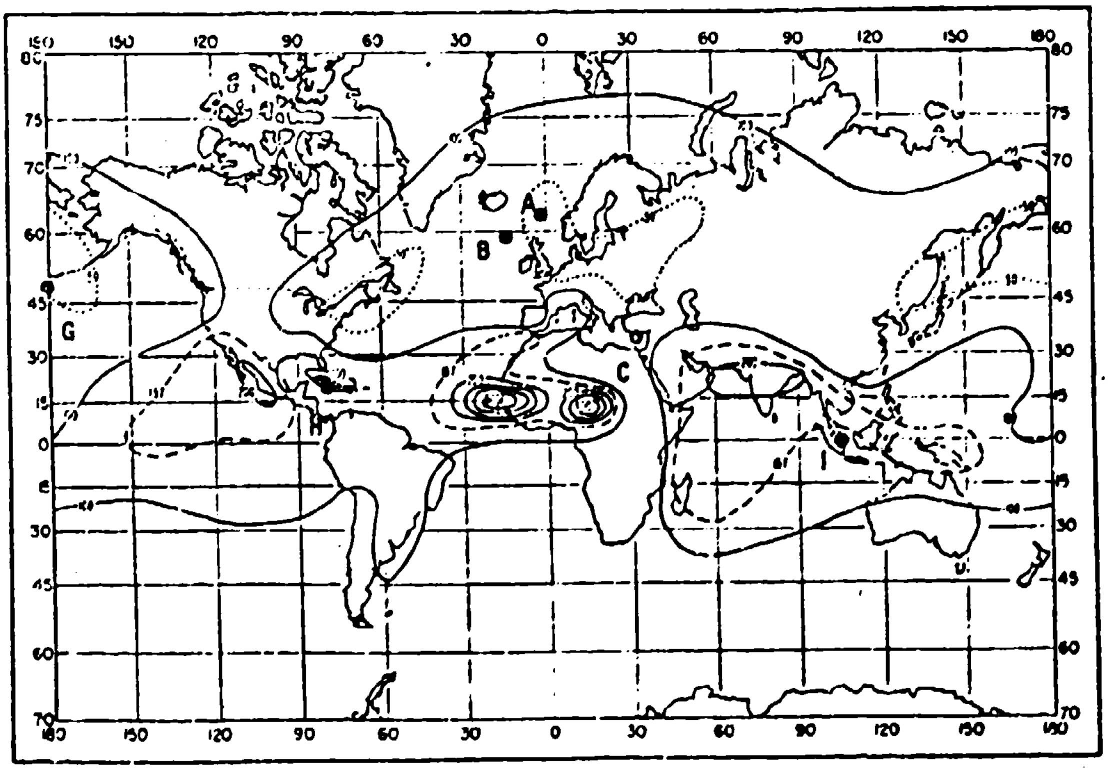
Percent of time trapping frequency < 1000 Mc's: February.



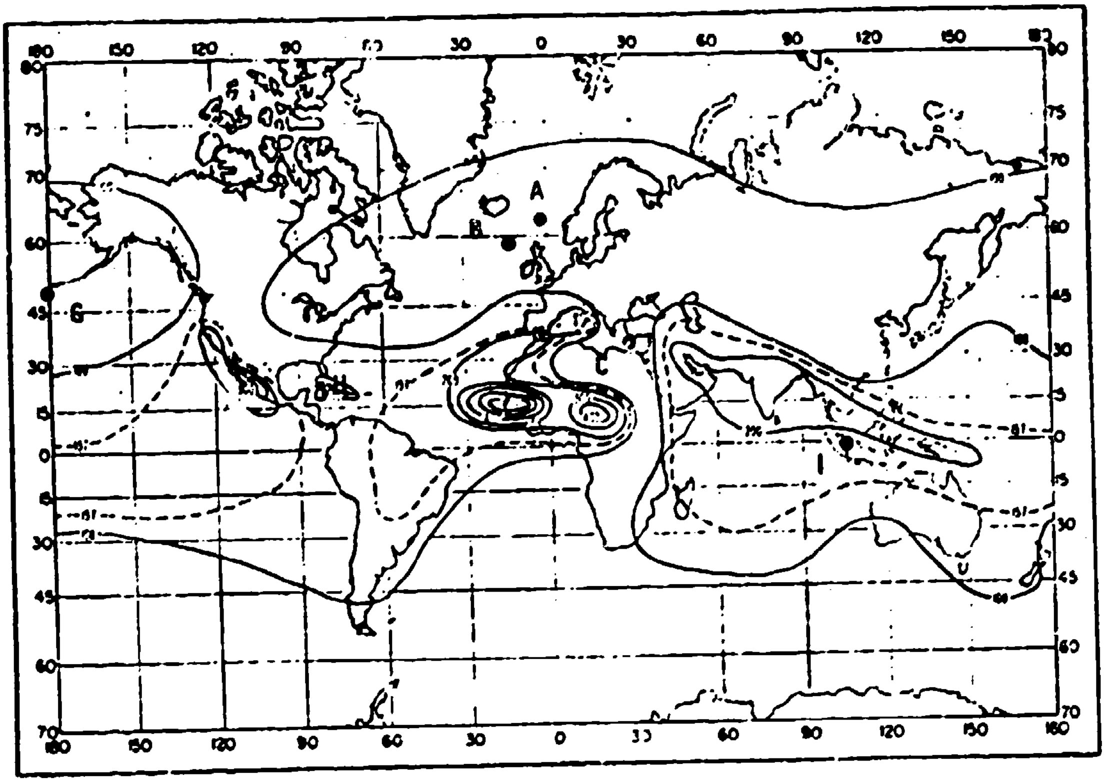
Percent of time trapping frequency < 800 Mc/s: February.



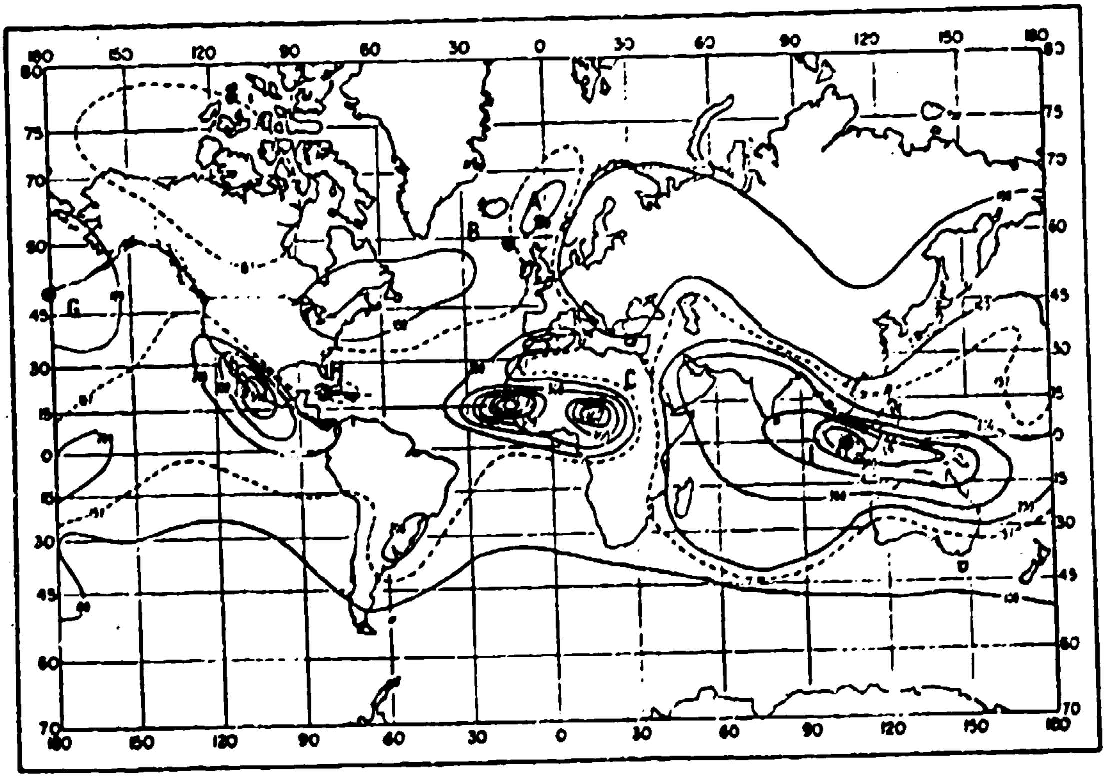
Lapse rate of refractivity (N/km) exceeded 25 percent of time for 100-m layer: February.



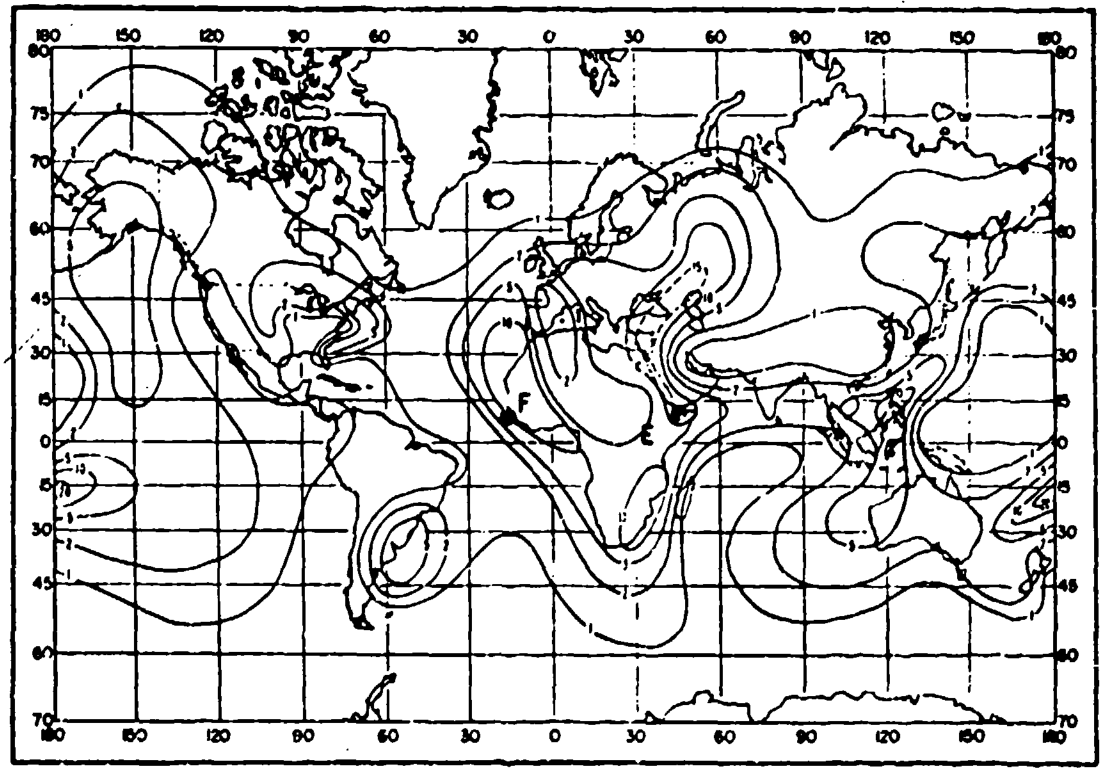
Lapse rate of refractivity (N/km) exceeded 10 percent of time for 100-m layer: February.



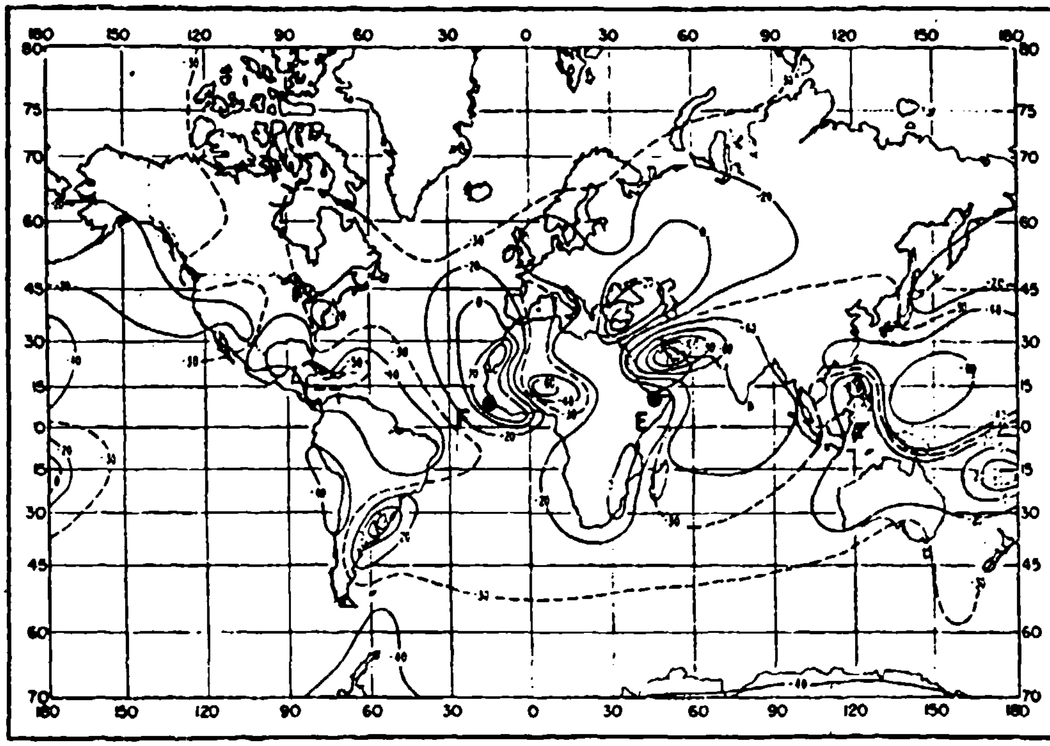
Lapse rate of refractivity (N/km) exceeded 5 percent of time for 100-m layer: February.



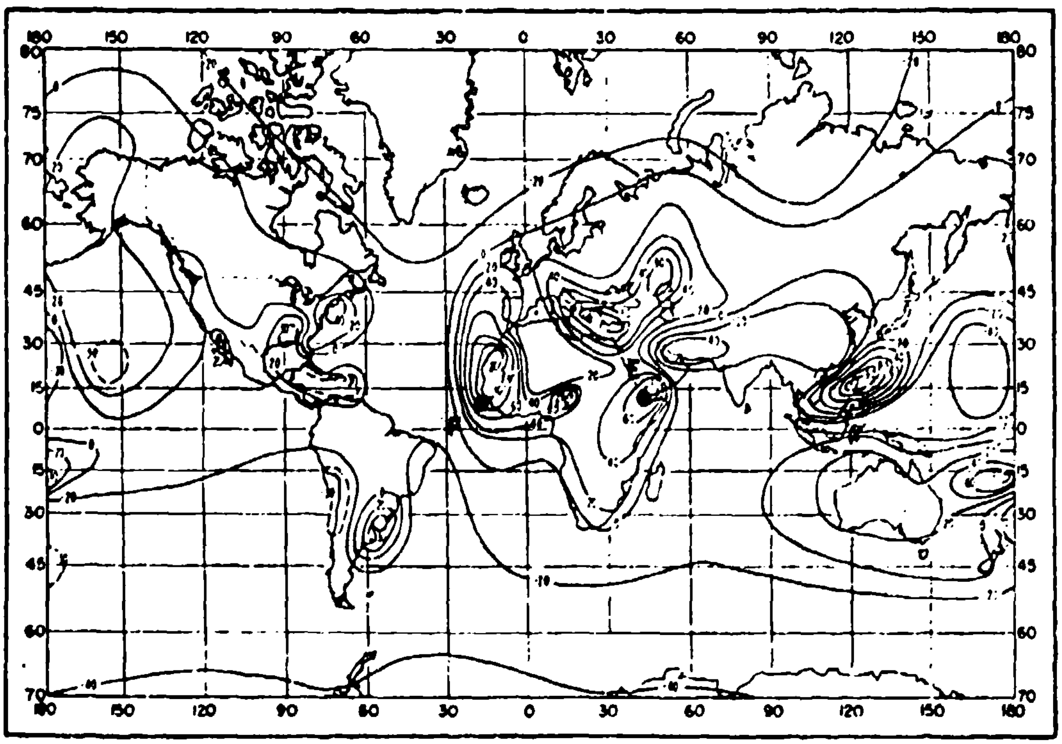
Lapse rate of refractivity (N/km) exceeded 2 percent of time for 100-m layer: February.



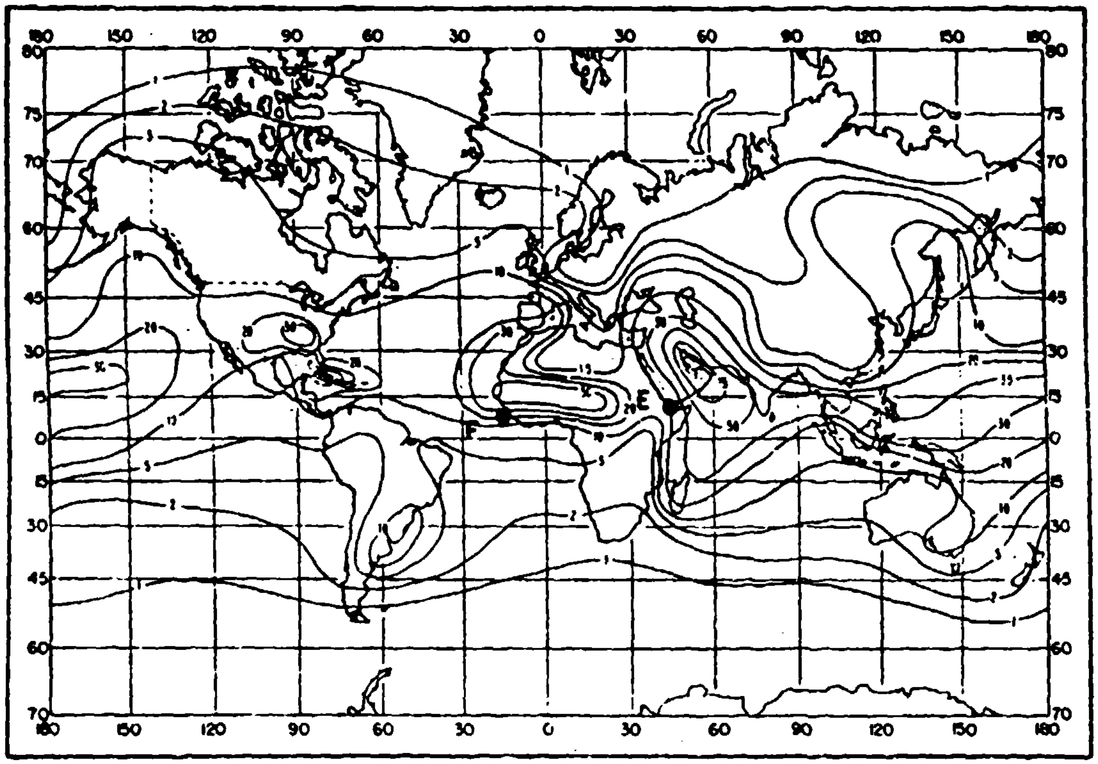
Percent of time gradient ≥ 0 (N/km): August.



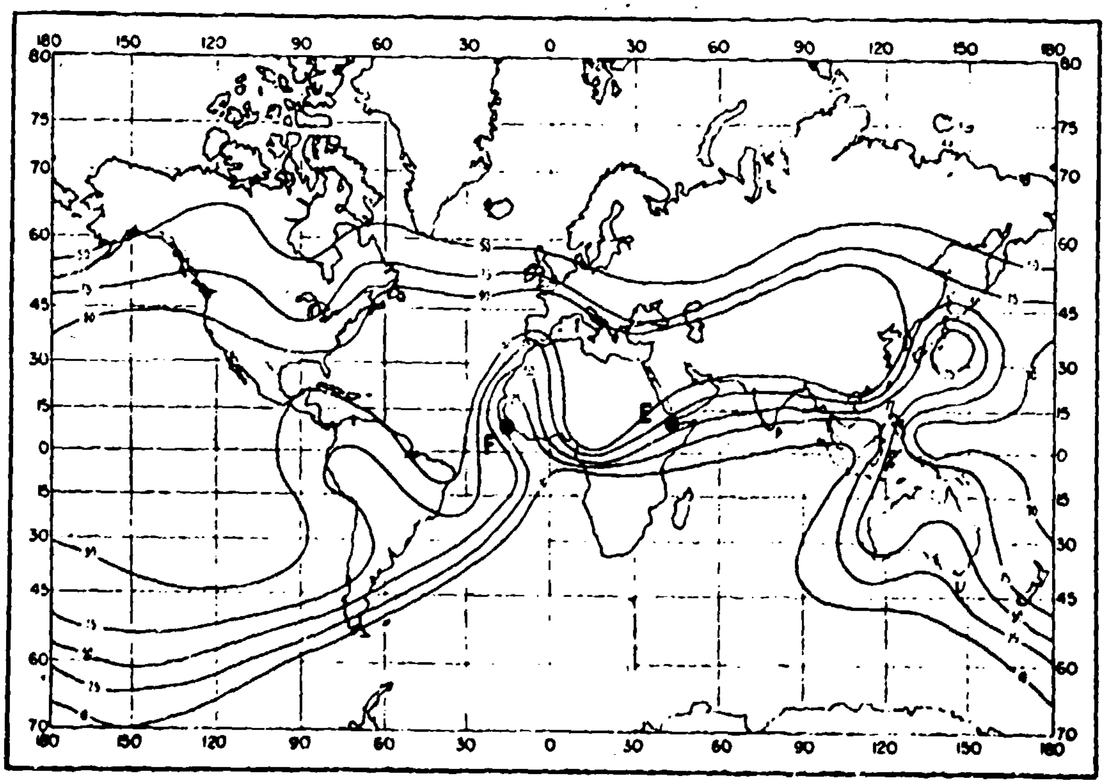
Gradient (N/km) exceeded 10 percent of the time for 100-m layer: August.



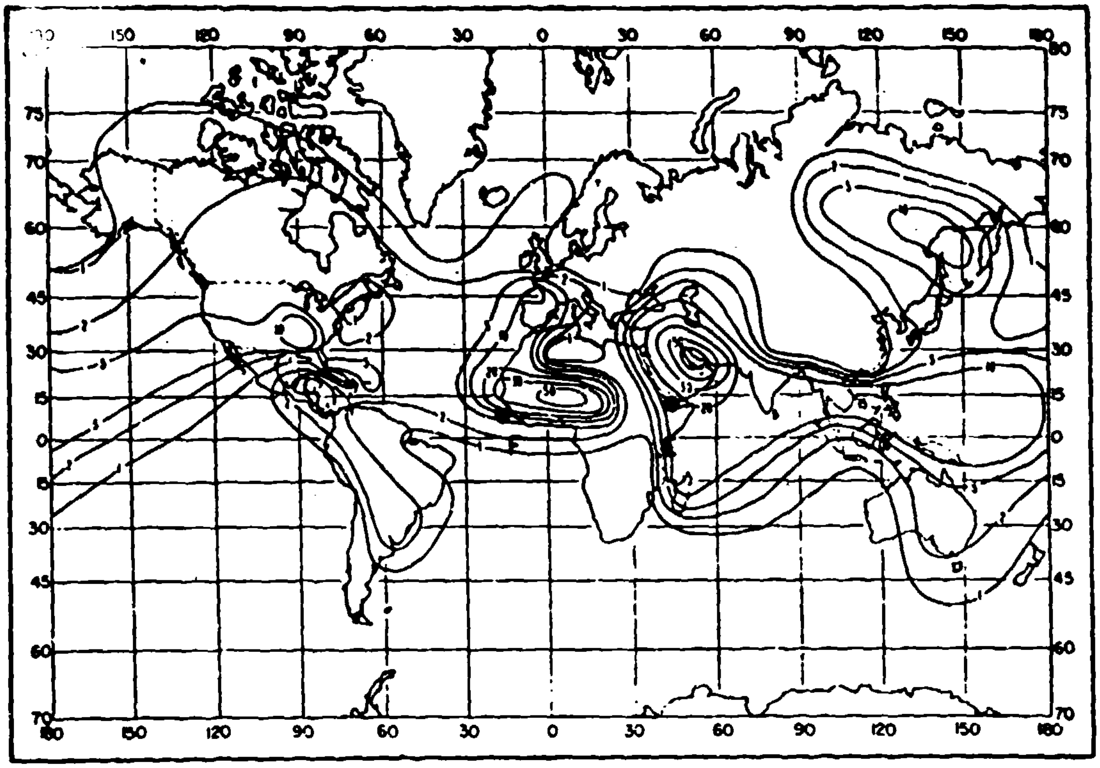
Gradient (N/km) exceeded 2 percent of the time for 100-m layer: August.



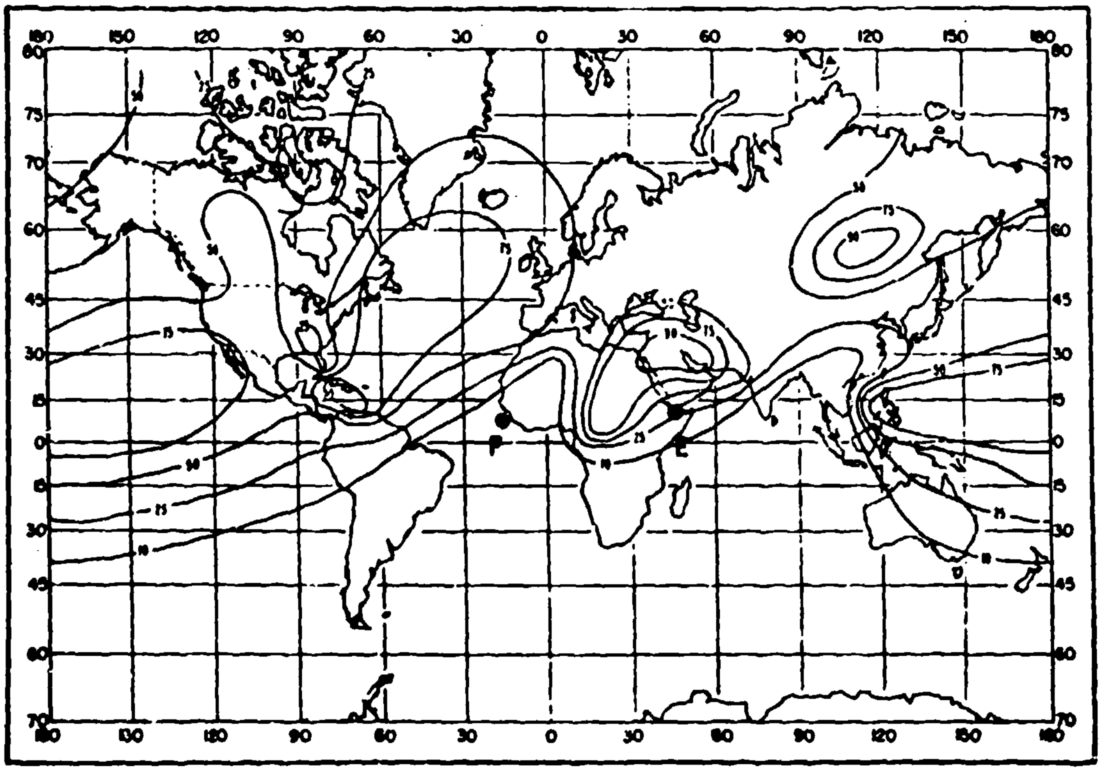
Percent of time gradient ≤ −100 (N/km): August.



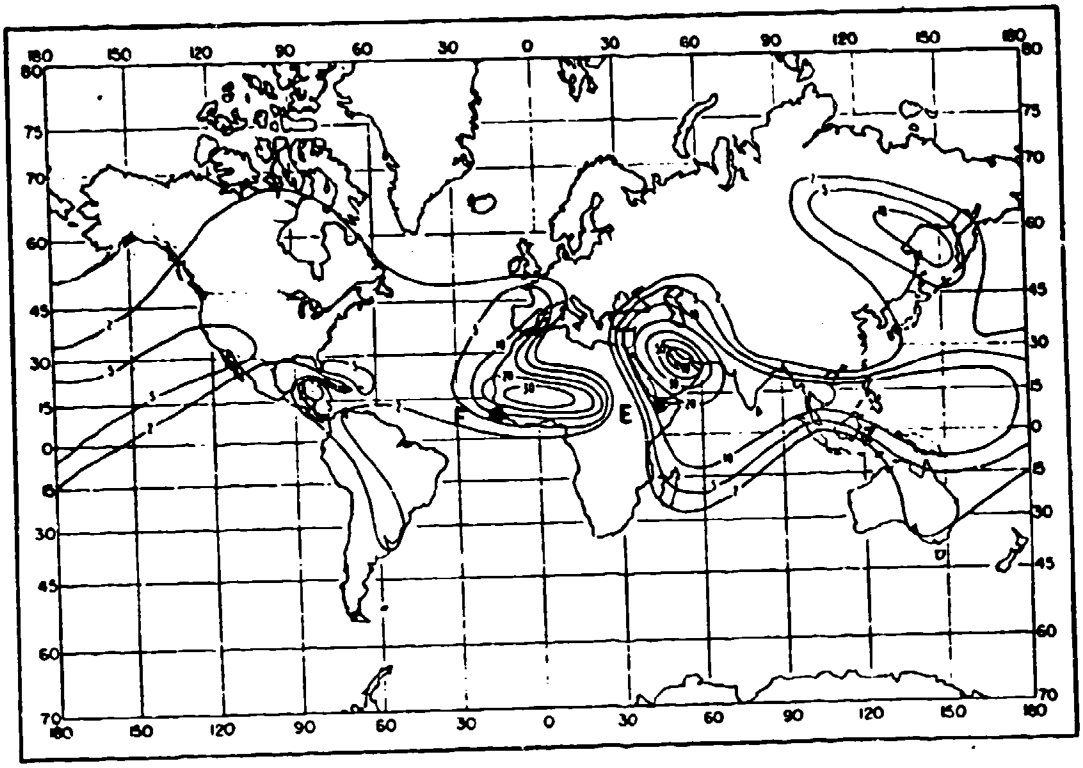
Percent of superrefractive layers thicker than 100 m: August.



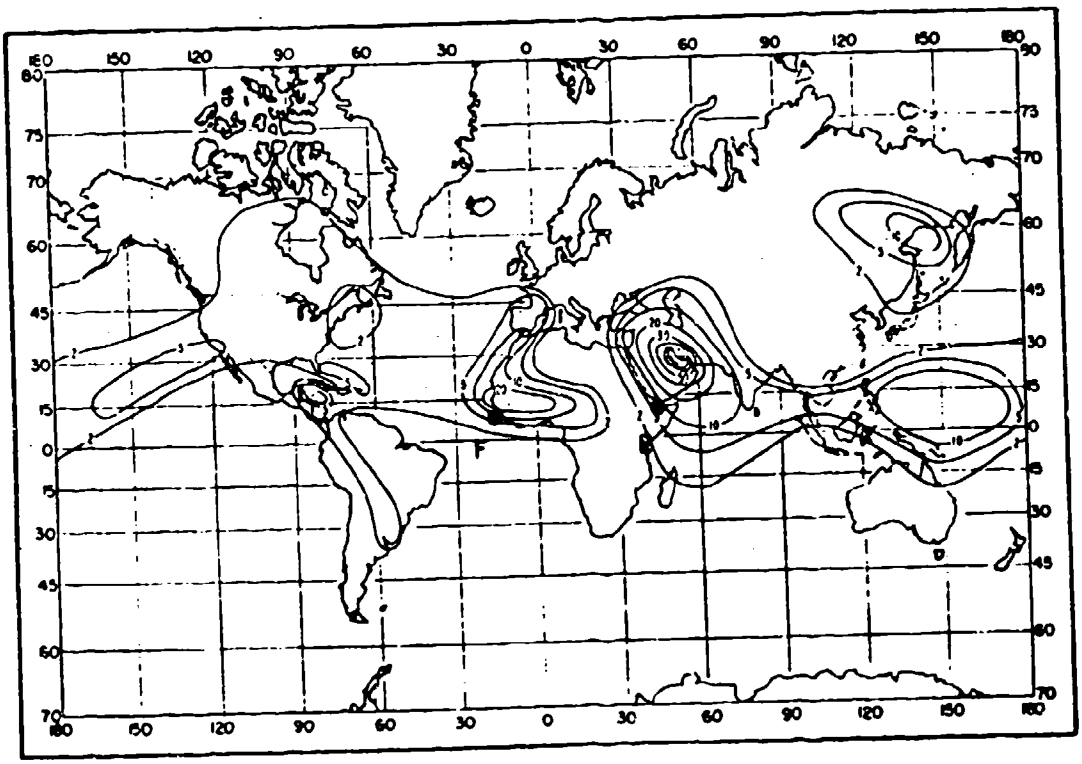
Percent of time gradient ≤ −157 (N/km): August.



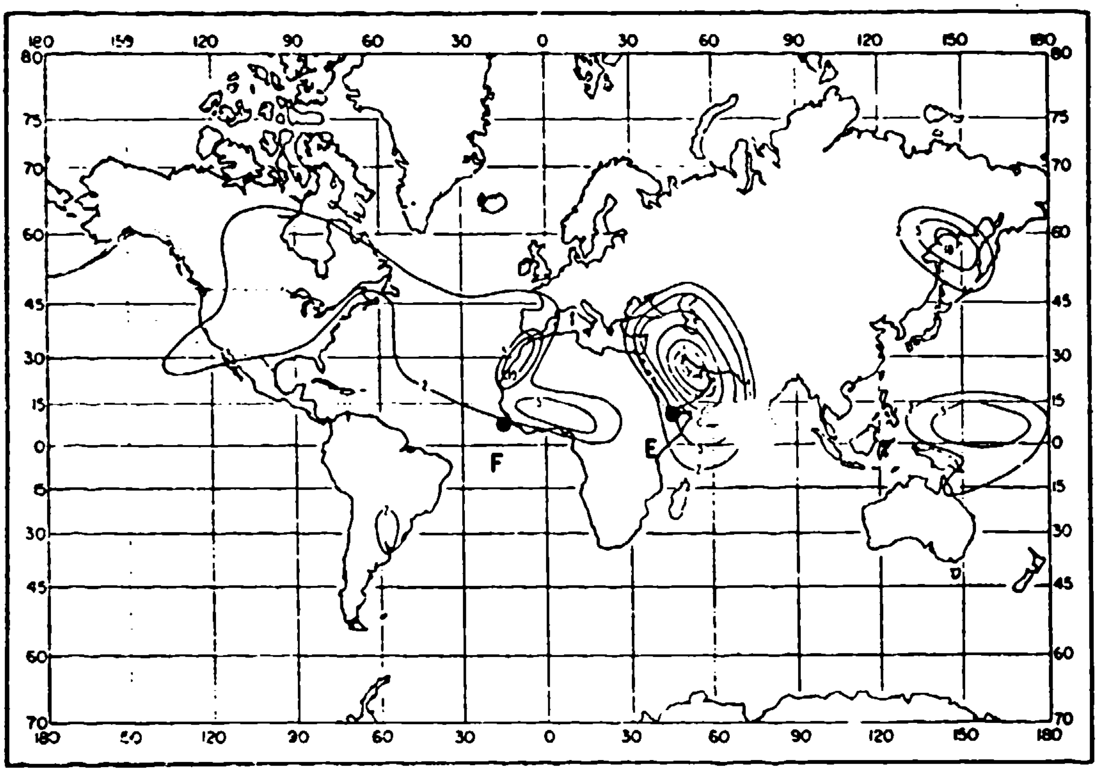
Percent of ducting layers thicker than 100 m: August.



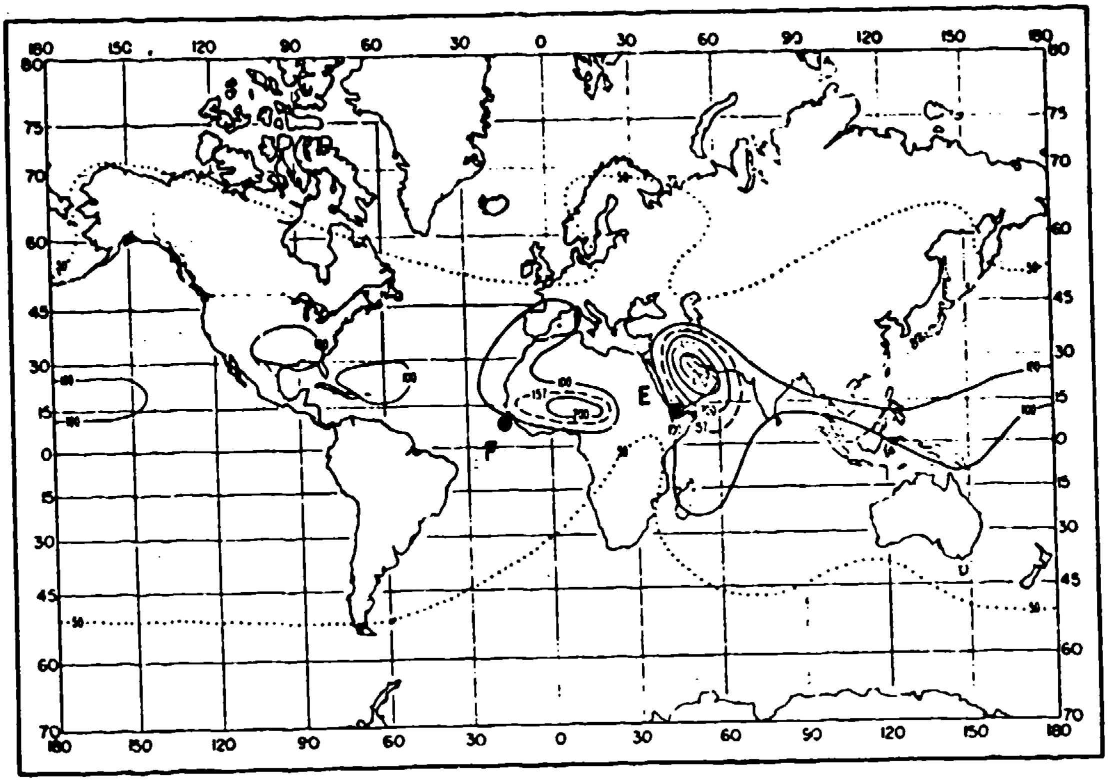
Percent of time trapping frequency < 3000 Mc/s: August.



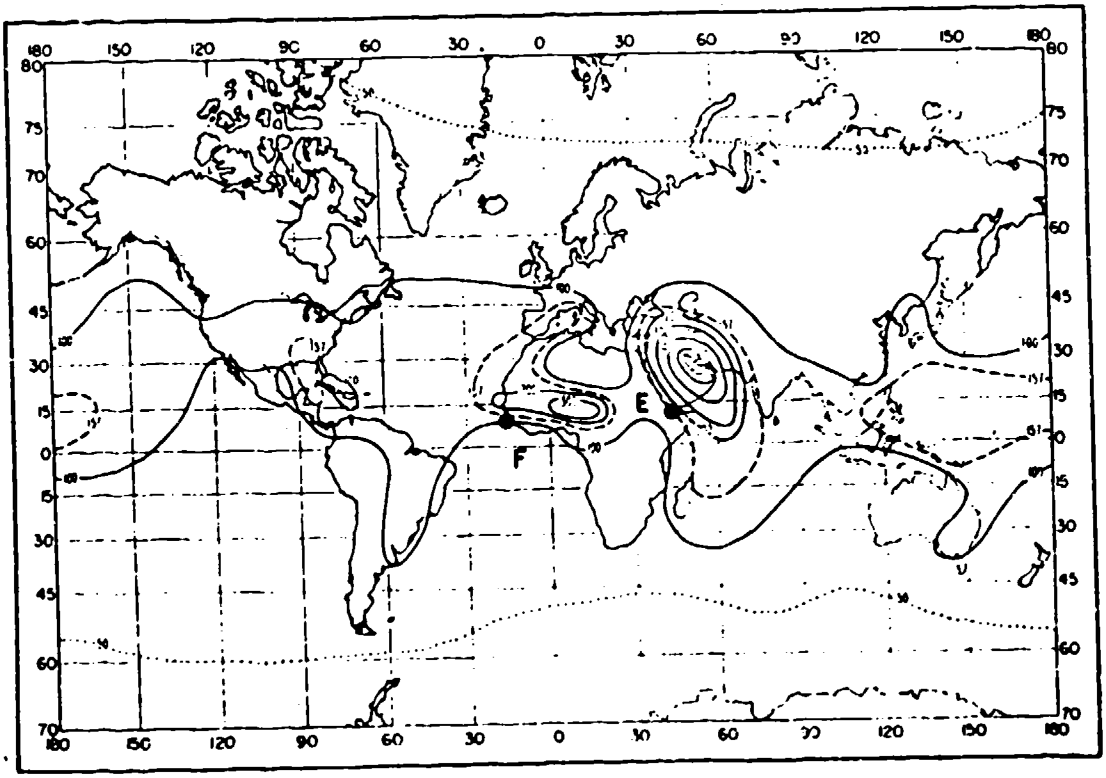
Percent of time trapping frequency < 1000 Mc/s: August.



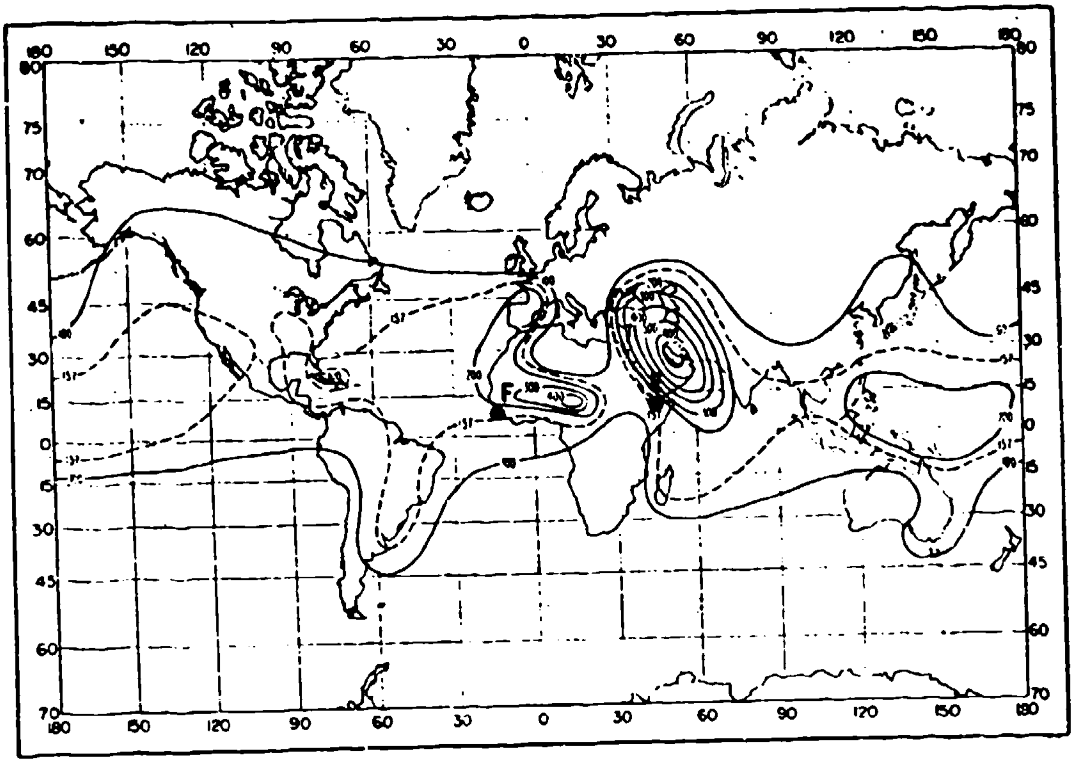
Percent of time trapping frequency < 300 Mc/s: August.



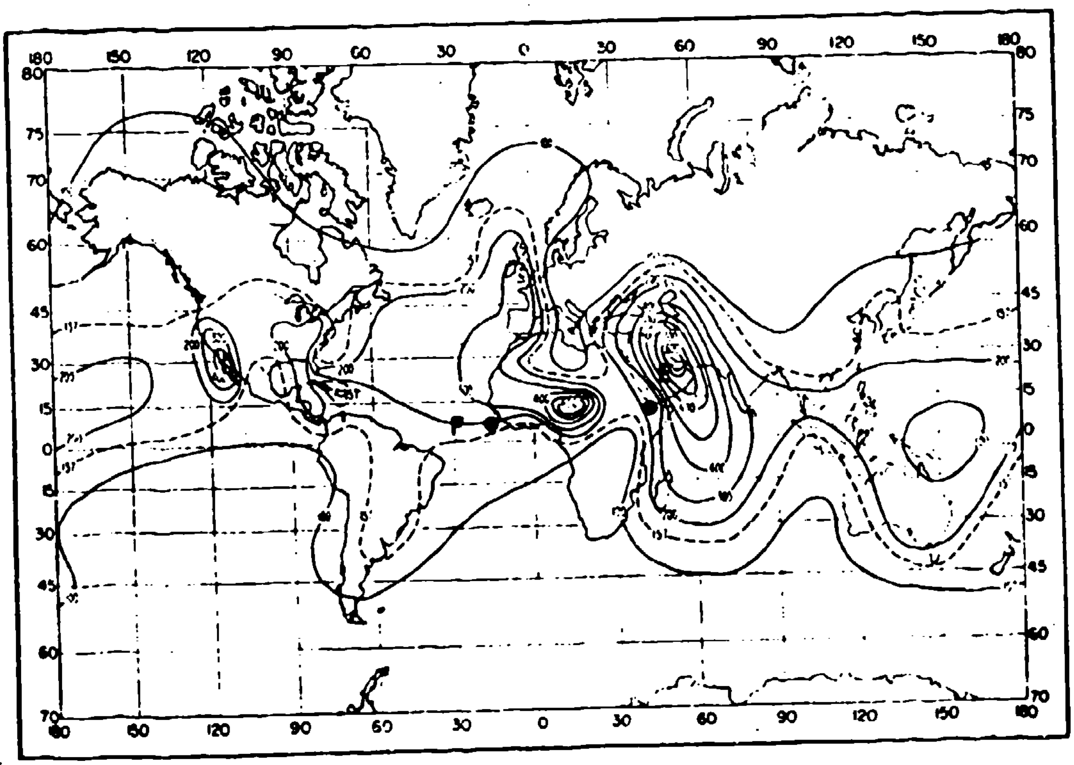
Lapse rate of refractivity (N/km) exceeded 25 percent of time for 100-m layer: August.



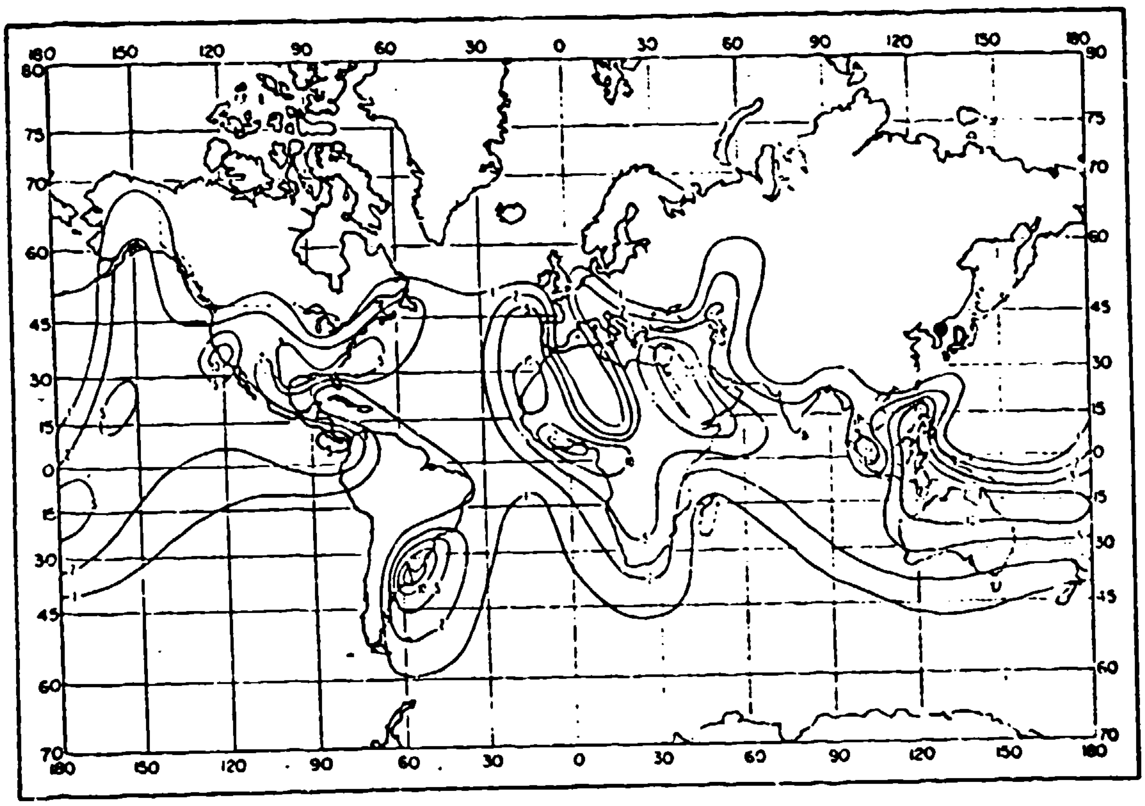
Lapse rate of refractivity (N/km) exceeded 10 percent of time for 100-m layer: August.



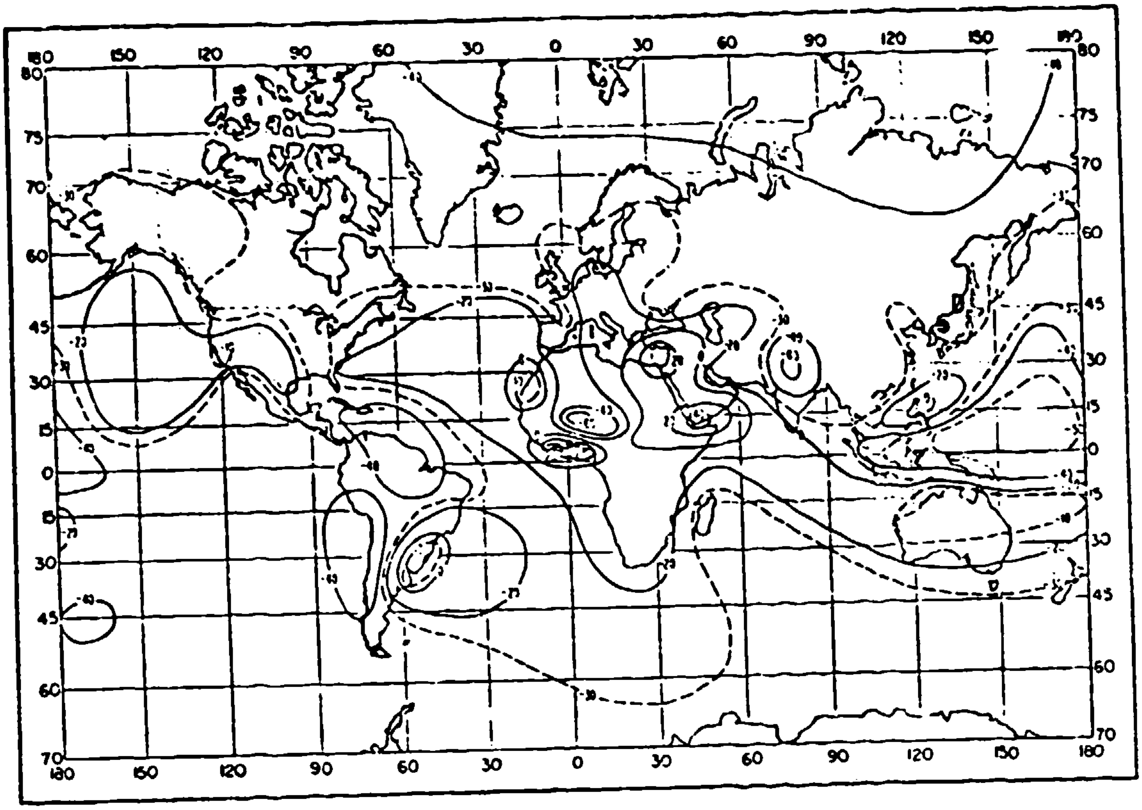
Lapse rate of refractivity (N/km) exceeded 5 percent of time for 100-m layer: August.



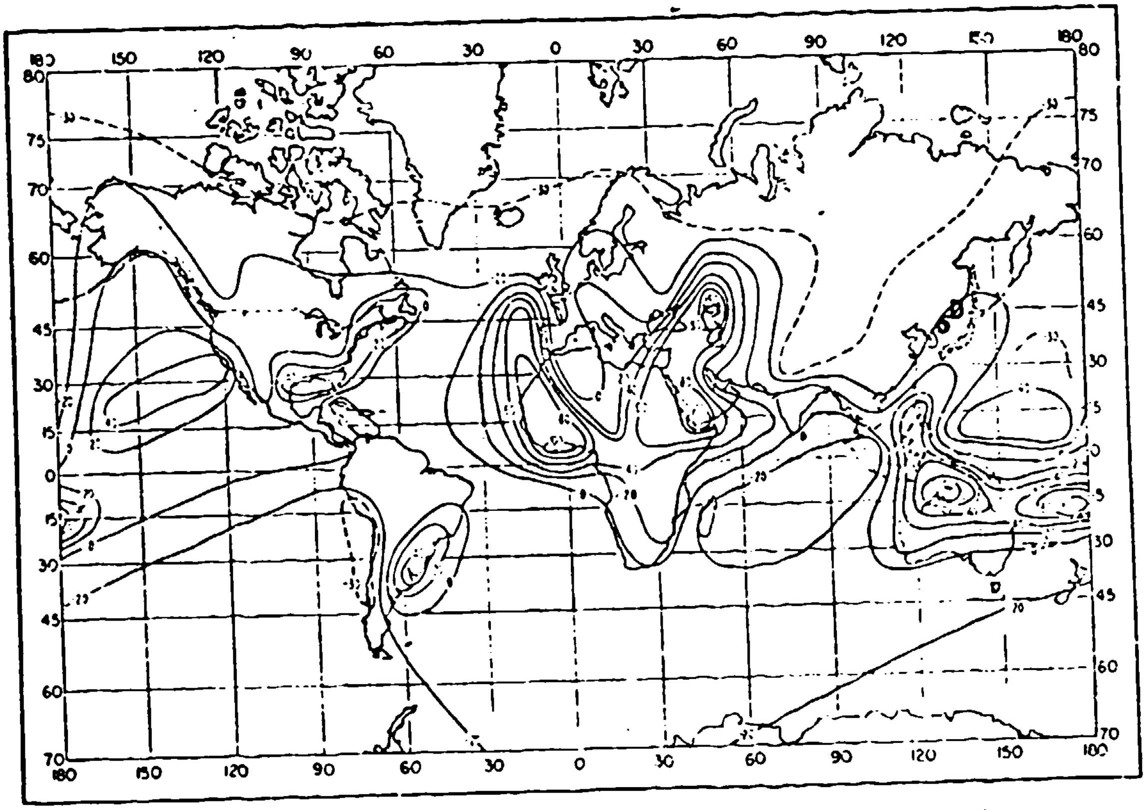
Lapse rate of refractivity (N/km) exceeded 2 percent of time for 100-m layer: August.



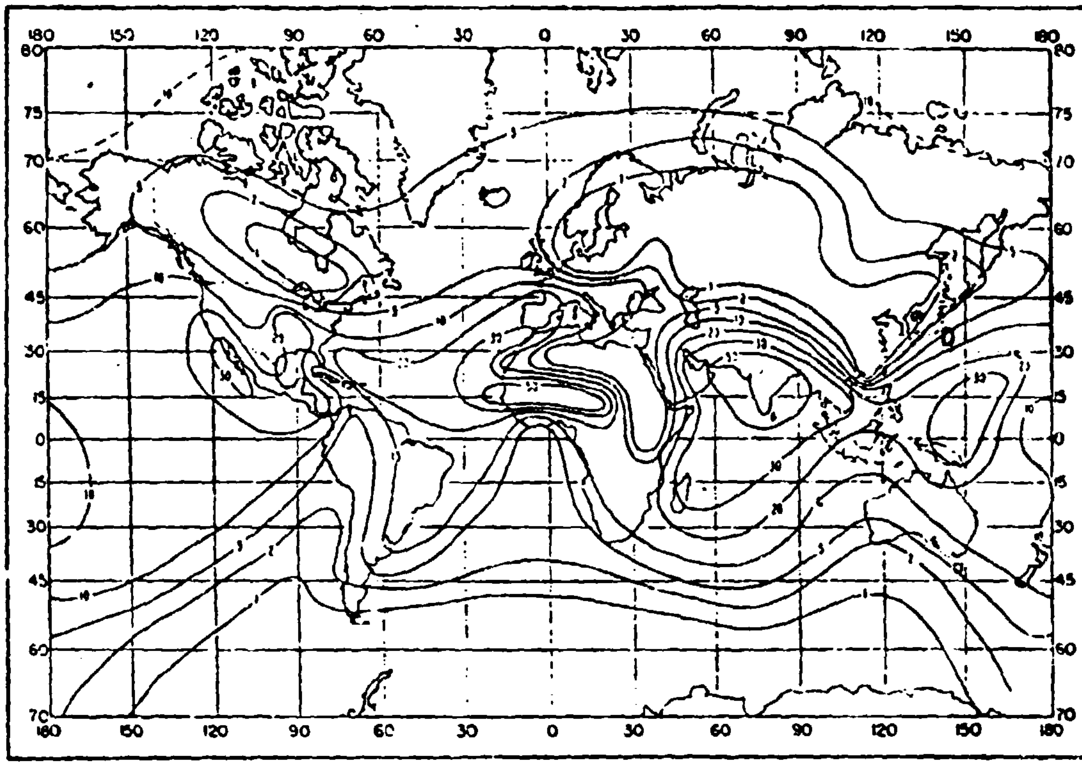
Percent of time gradient ≥ 9 (N/km): November.



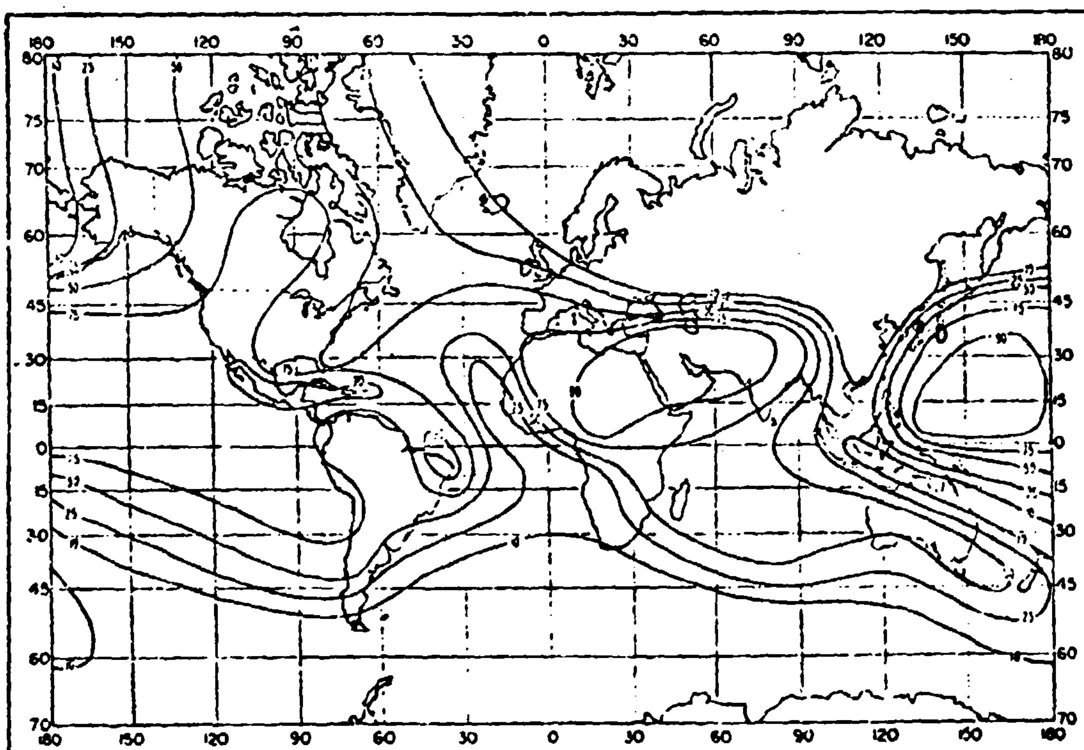
Gradient (N/km) exceeded 10 percent of the time for 100-m layer: November.



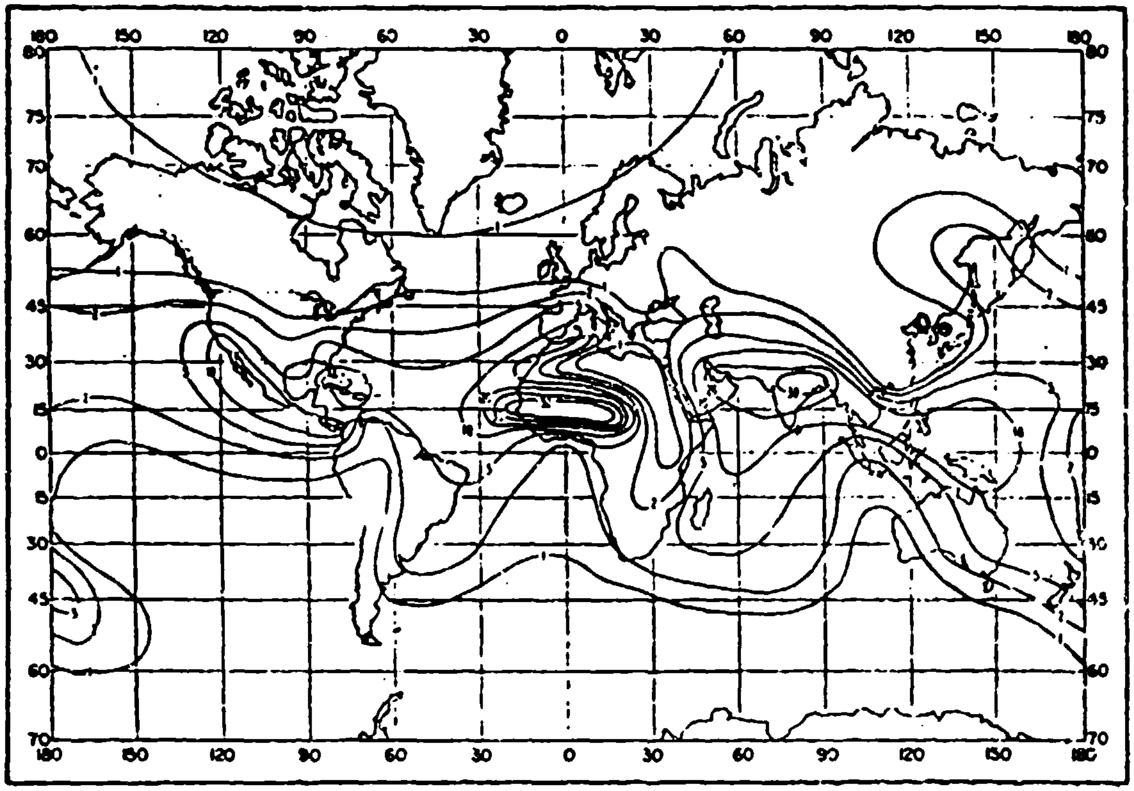
Gradient (N/km) exceeded 2 percent of the time for 100-m layer: November.



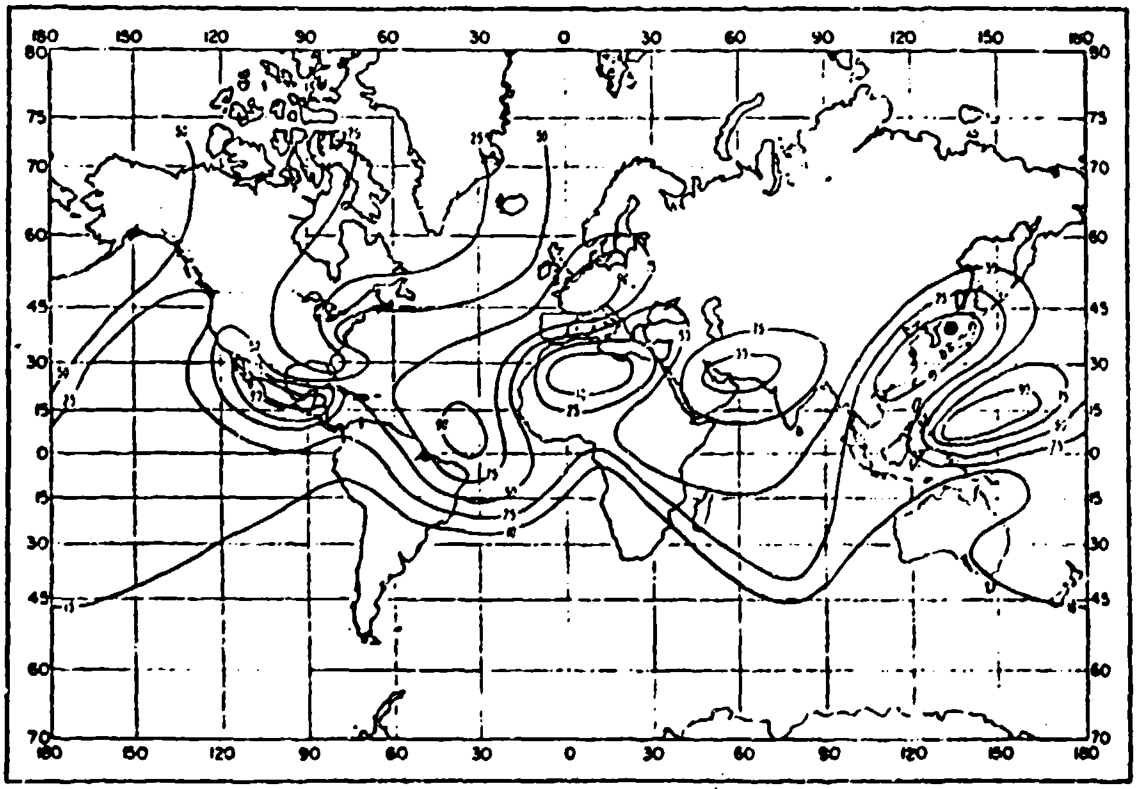
Percent of time gradient ≤ −100 (N/km): November.



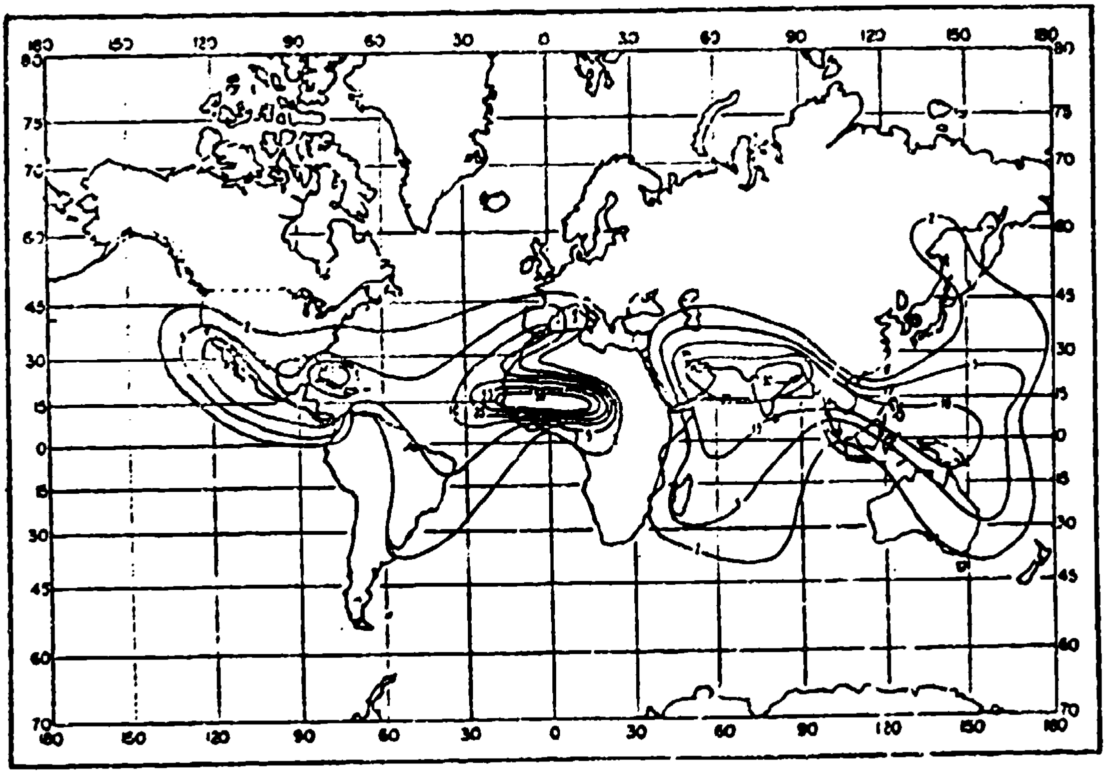
Percent of superrefractive layers thicker than 100 m: November.



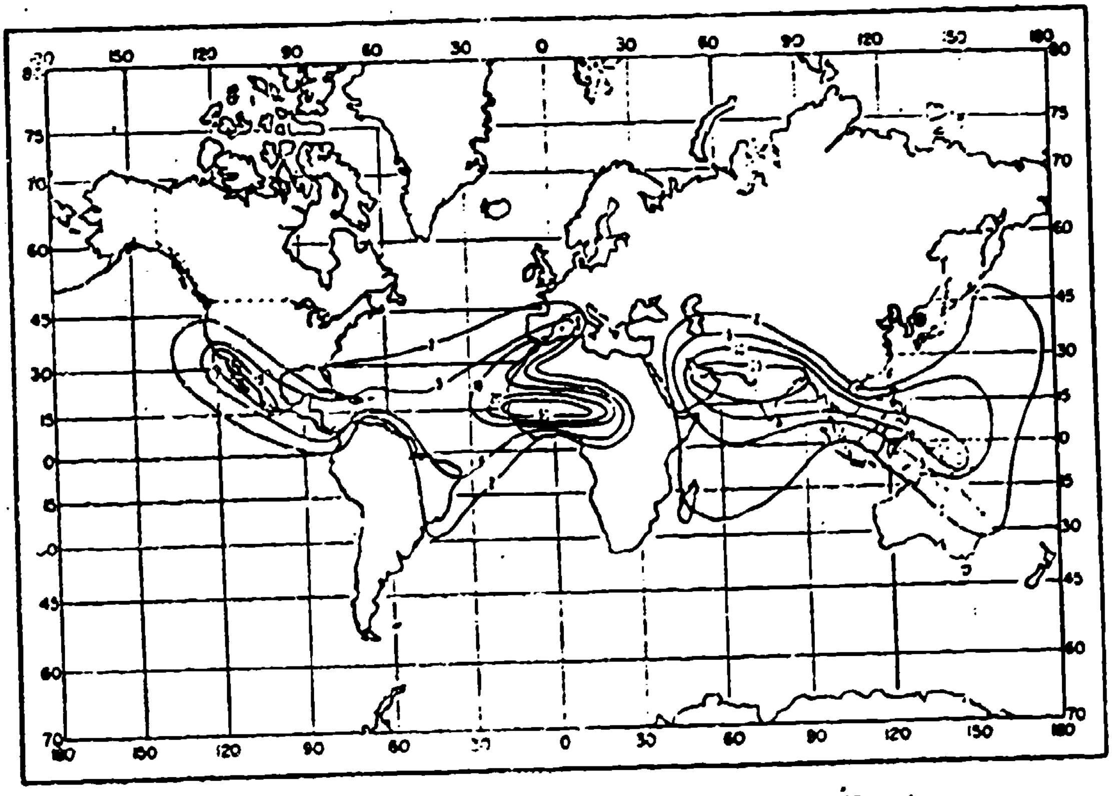
Percent of time gradient ≤ −157 (N/km): November.



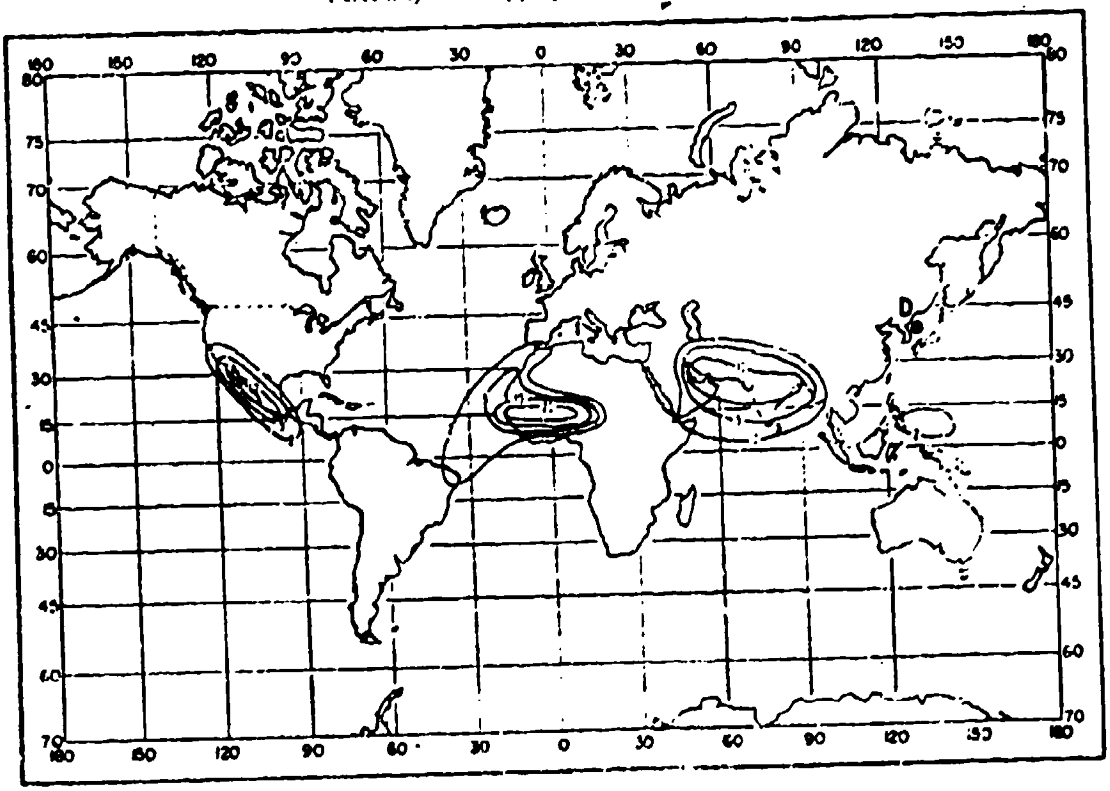
Percent of ducting layers thicker than 100 m: November.



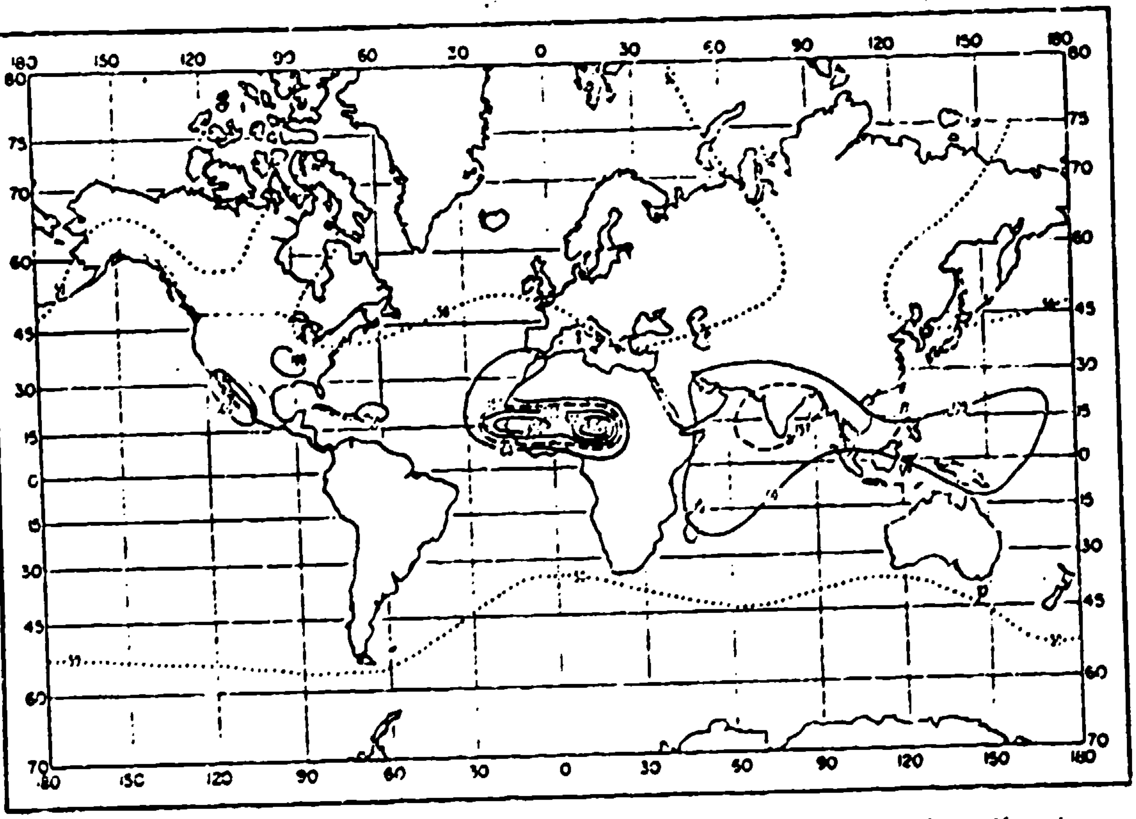
Percent of time trapping frequency < 8000 Mc/s: November.



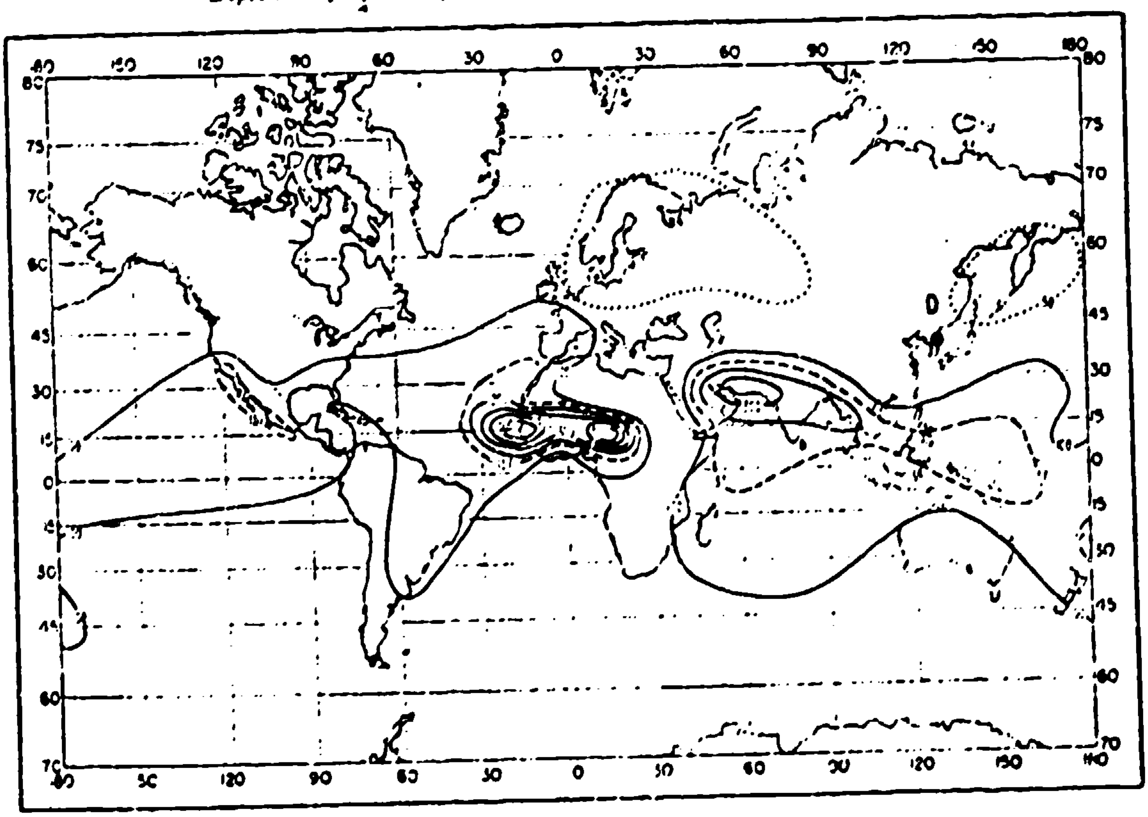
Percent of time trapping frequency < 1000 Mc/s: November.



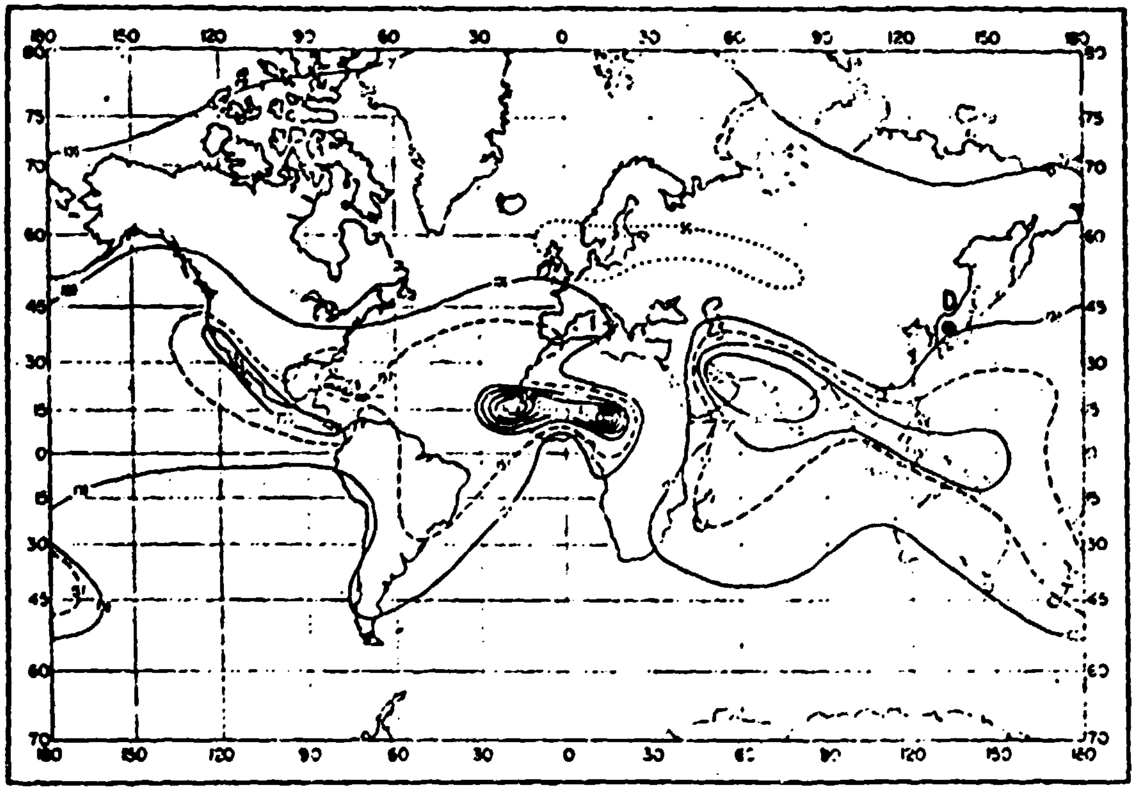
Percent of time trapping frequency < 800 Mc/s: November.



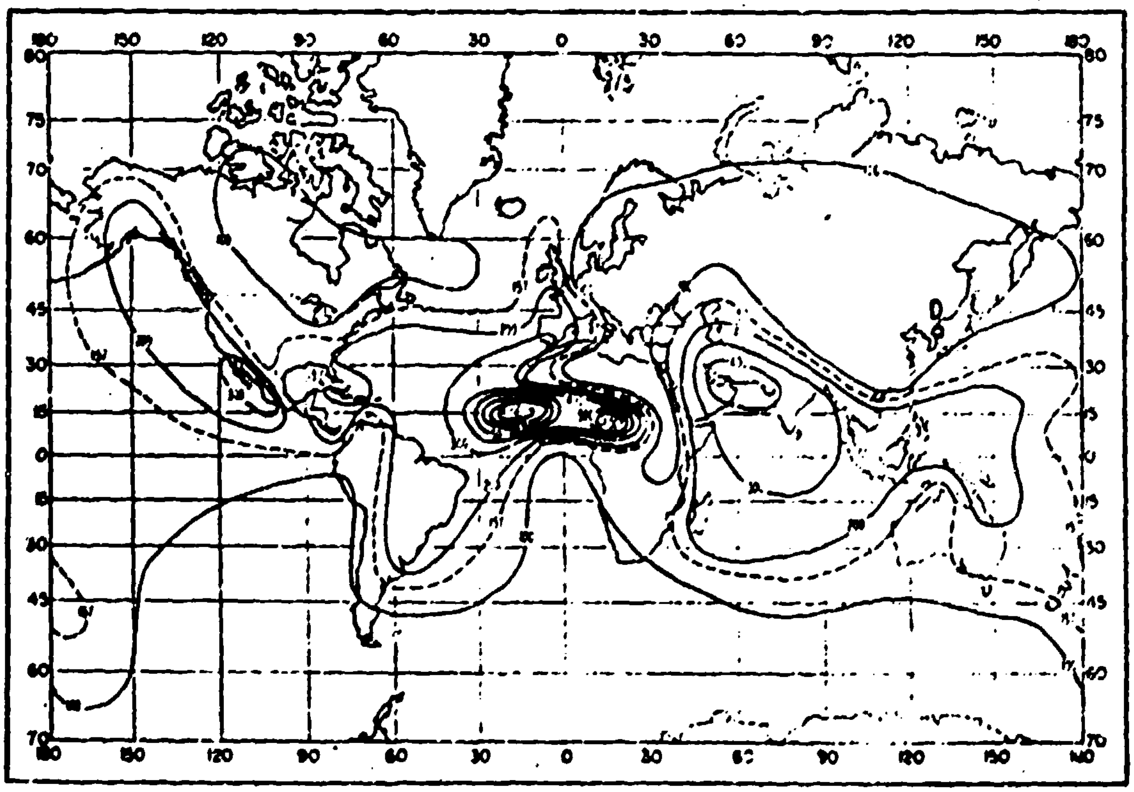
Lapse rate of refractivity (N/km) exceeded 25 percent of time for 100-m layer: November.



Lapse rate of refractivity (N/km) exceeded 10 percent of time for 100-m layer: November.

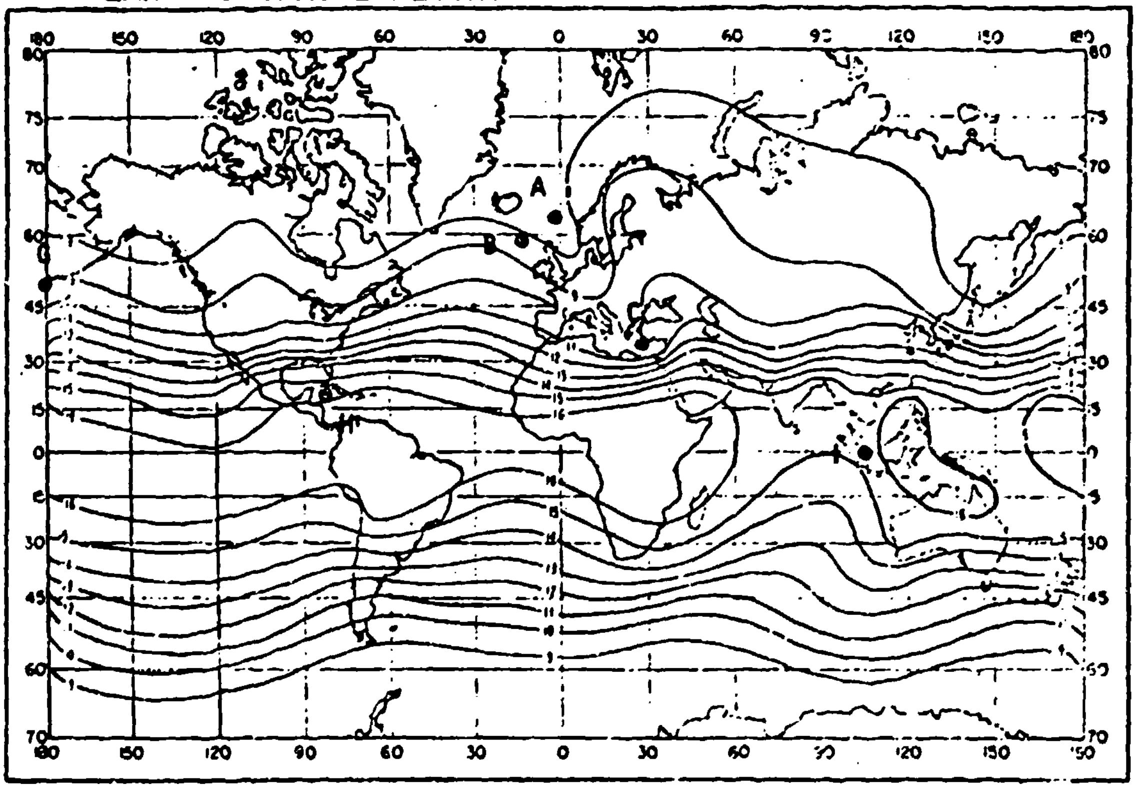


Lapse rate of refractivity (N/km) exceeded 5 percent of time for 100-m layer: November.

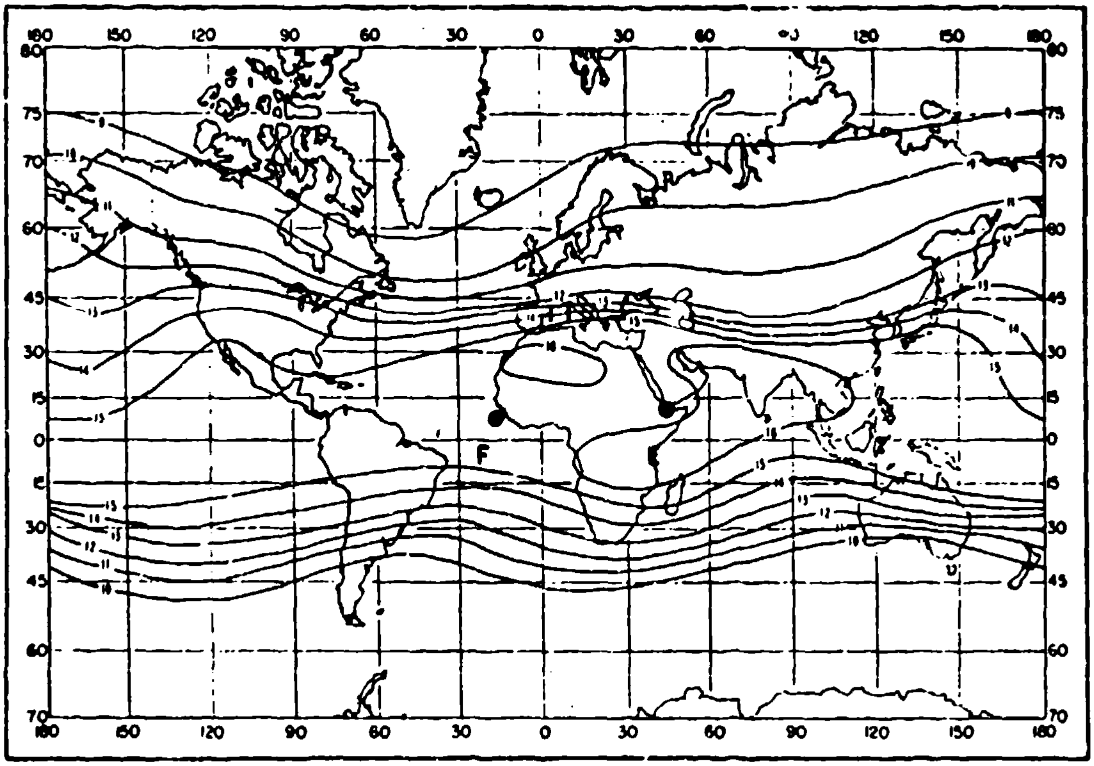


Lapse rate of refractivity (N/km) exceeded 2 percent of time for 100-m layer: November.

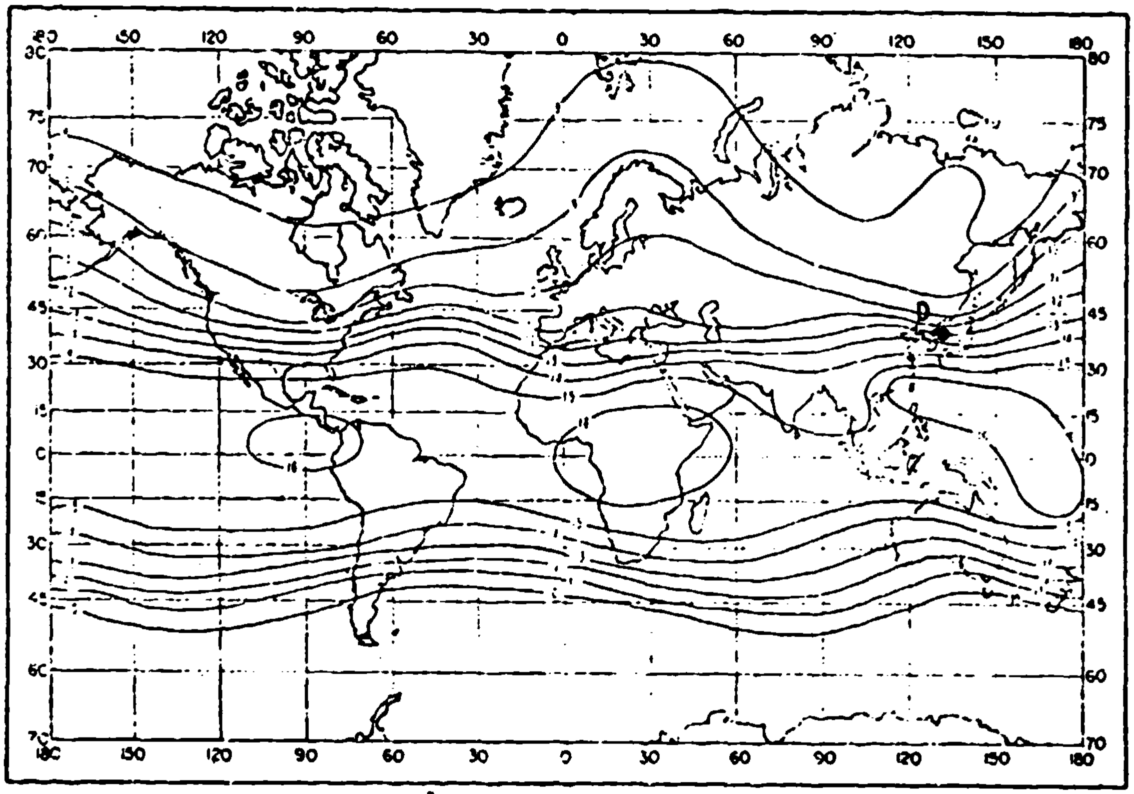
d. MEAN TROPOPAUSE HEIGHT



Tropopause heights (km), based on temperature lapse rate: February.



Tropopause heights (km), based on temperature lapse rate: August.



Tropopause heights (km), based on temperature lapse rate: November.

APPENDIX L

MISCELLANEOUS PROPERTIES

Figure L-1 provides a daylight-darkness chart, extracted from Reference 3, for the Northern Hemisphere. Locations A through I are noted in the latitude scales on the left and right of the chart. The chart assumes that daylight is the period of time from sunrise to sunset. For example, the daylight of February 15th of any year at Location A (63°N) is approximately 8 hours and 45 minutes. As stated in Reference 3, additional light, as at twilight, may be useful for some purposes, say for instance aircraft landings. Also, it is noted that some error in the chart for latitudes about 60° (Location A) is possible because of the dependence of duration of daylight on local atmospheric conditions and refraction.

Figure L-2, extracted from Reference 2, provides a theoretical prediction of the depth of wave action as a function of wave period. The figure is derived from the assumption

$$\text{wavelength (in feet)} = 5.12 \cdot (\text{wave period})^2 \text{ (in seconds}^2\text{)}$$

and that the depth at which wave action becomes negligible equals one half the wavelength while the depth of no wave action equals the wavelength.

Figure L-3, extracted from Reference 20, provides estimates of survival times of a person in cold water. Ordinary clothes and life preserver are assumed.

Figure L-4, extracted from the Sea Environmental Manual, a draft report to be published during 1979, provides an identification of sea severity using sea state delineators. Significant wave heights (average of one-third highest double amplitudes) and average sustained wind speeds are given for each sea state. The percent frequencies of occurrence are for the North Atlantic between 40 to 60°N during the winter months (December to February).

Wind speeds, such as those given on Figure L-4, are representative of a gradient and must be specified for a given height above the sea surface. The wind velocity gradient can be approximated by the following expression obtained from Reference 26:

$$\nu_B = \nu_A \left(H_B/H_A\right)^{1/7}$$

where ν is the wind speed and H is the height above the sea surface at point A or B.

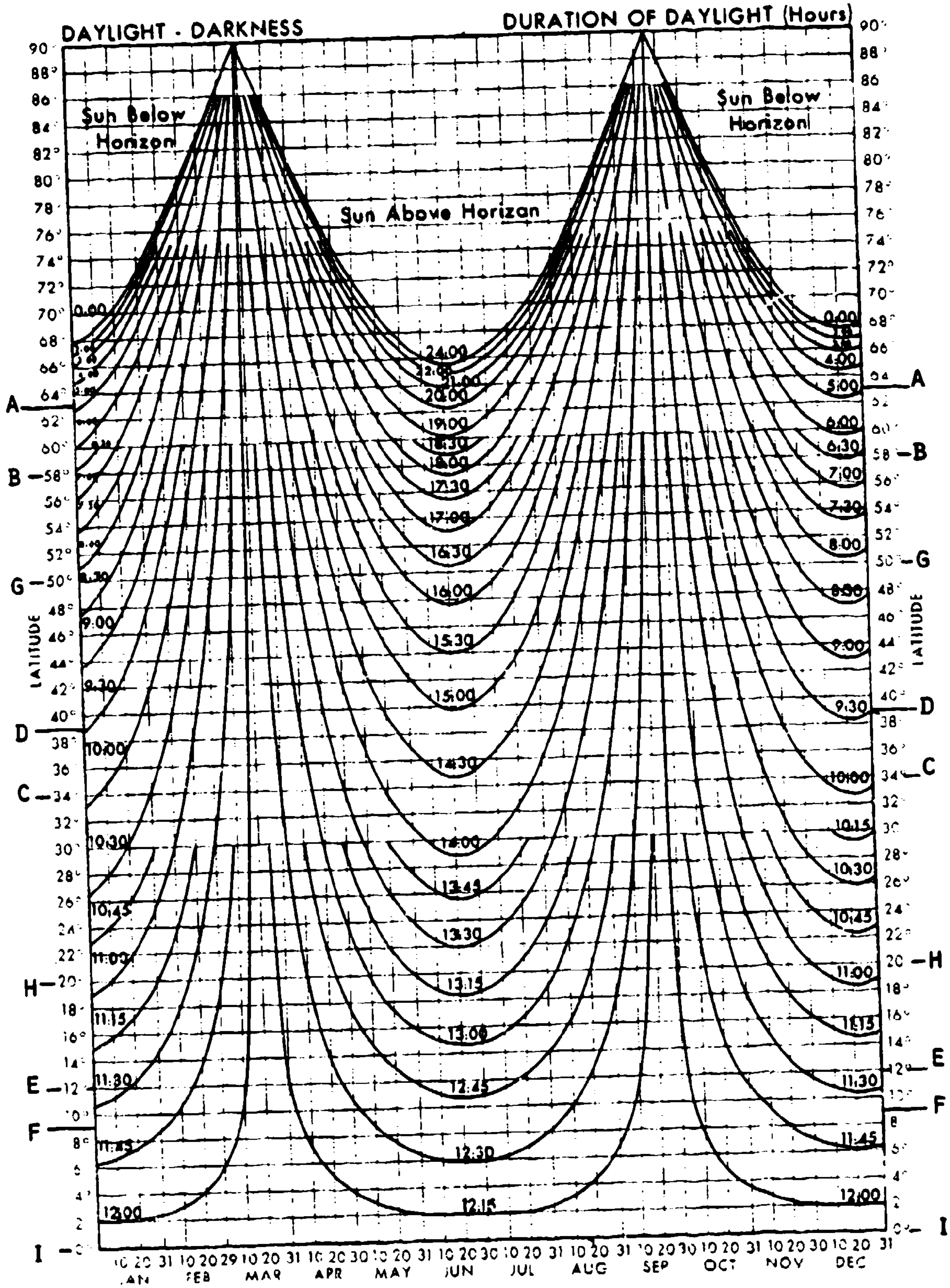


Figure L-1 - Daylight-Darkness Chart
for the Northern Hemisphere

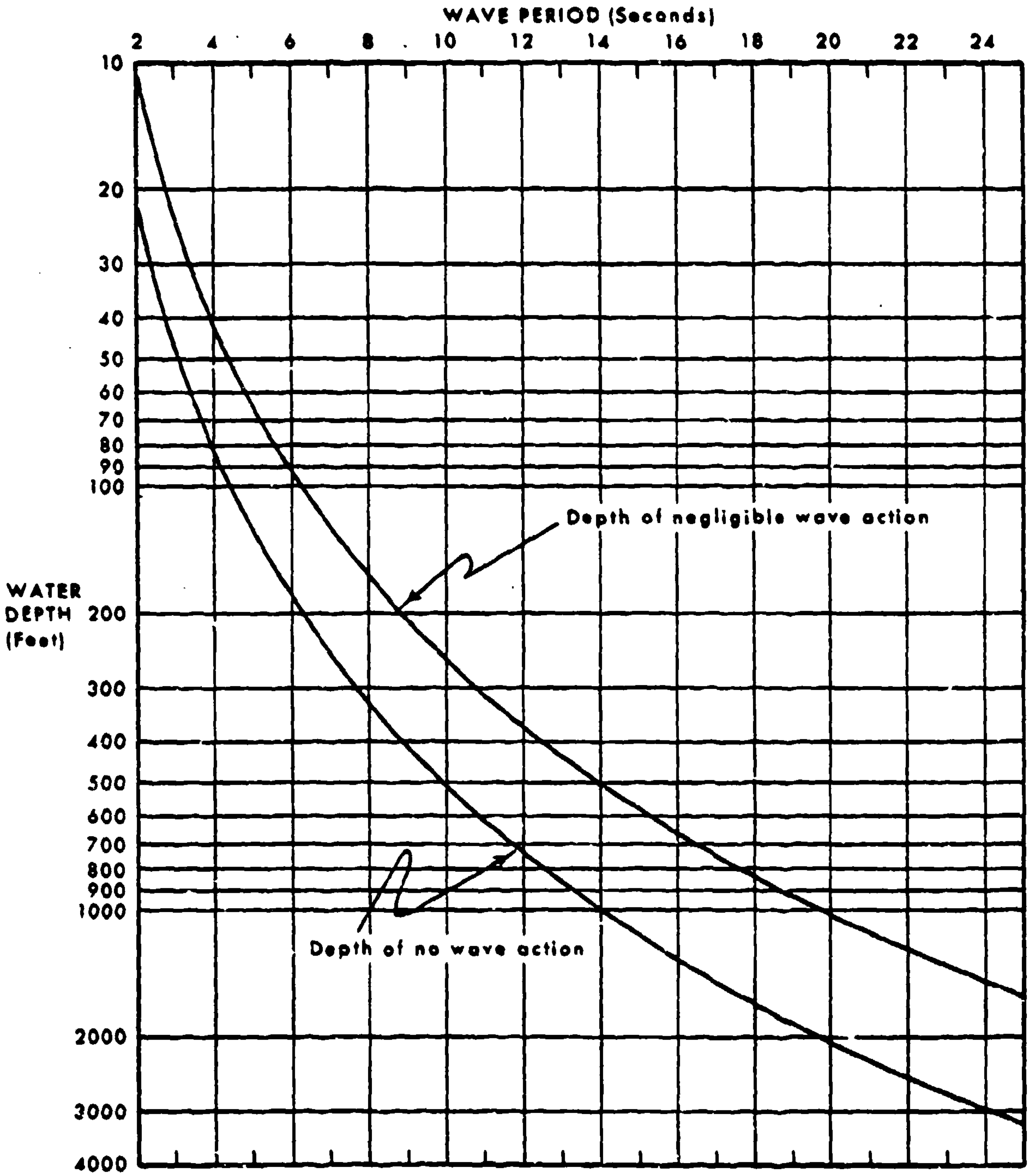


Figure L-2 - Depth of Wave Action as a Function of Wave Period

Water Temperature	*Exhaustion or Unconsciousness*	*Expected Time of Survival*
< 0°C	< 15 min	< 15 to 45 min
0 to 5°C	15 to 30 min	30 to 90 min
5 to 10°C	30 to 60 min	1 to 3 hrs
10 to 15°C	1 to 2 hrs	1 to 6 hrs
15 to 20°C	2 to 7 hrs	2 to 40 hrs
20 to 25°C	3 to 12 hrs	3 to indefinite hrs
> 25°C	Indefinite	Indefinite

Figure L-3 - Estimated Human Survival Times in Cold Water

WINTER, NORTH ATLANTIC (40 TO 60°N)			
Sea State	Significant Wave Height, Feet	Mean Wind Speed,* Knots	Percent Frequency Occurrence
0 to 1	0 to 1.9	0 to 10	1.7
2	1.9 to 4.1	10 to 14	7.2
3	4.1 to 5.7	14 to 17	8.6
4	5.7 to 7.4	17 to 19	11.6
5	7.4 to 13.0	19 to 25	42.0
6	13.0 to 20.8	25 to 32	20.3
7	20.8 to 40.3	32 to 44	8.6
8	40.3 to 61.6	44 to 55	∿ 0.0

*Note: Wind Speed is taken as the mean sustained speed for 10 minutes at 32.8 feet above the surface.

Figure L-4 - Sea State Chart for Wintertime North Atlantic (40 to 60°N)

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